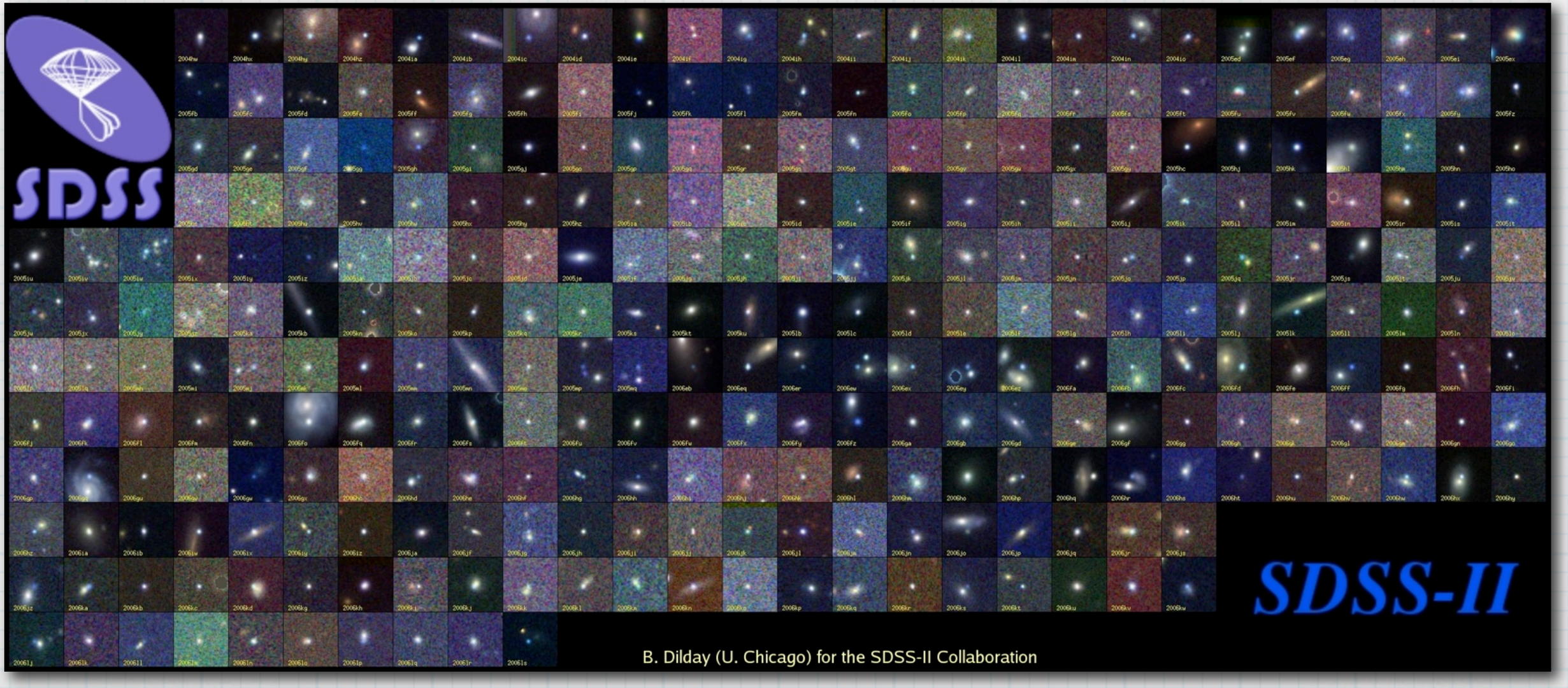
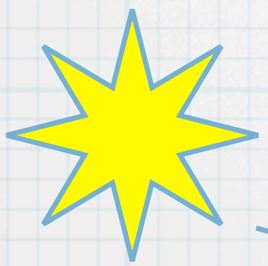
SDSS-II Supernova Survey

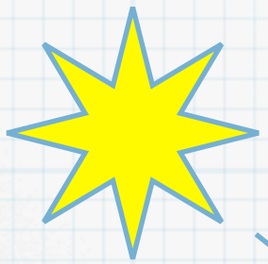
Masao Sako (Penn)
for the SDSS-II Collaboration and SN Spectroscopic Follow-up Teams

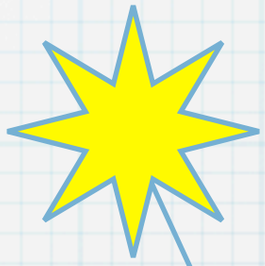


Type Ia Supernovae as standard candles.

thermonuclear explosions of white dwarfs







$$F = \frac{L}{4\pi d_L^2}$$

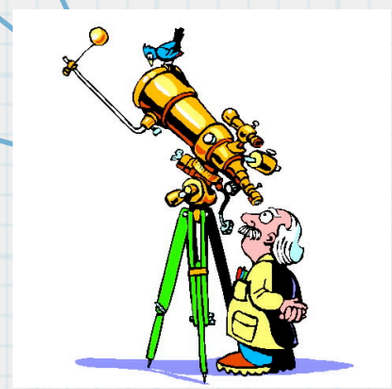
"known"

luminosity-distance (depends on cosmology)

d_{L1}

d_{L2}

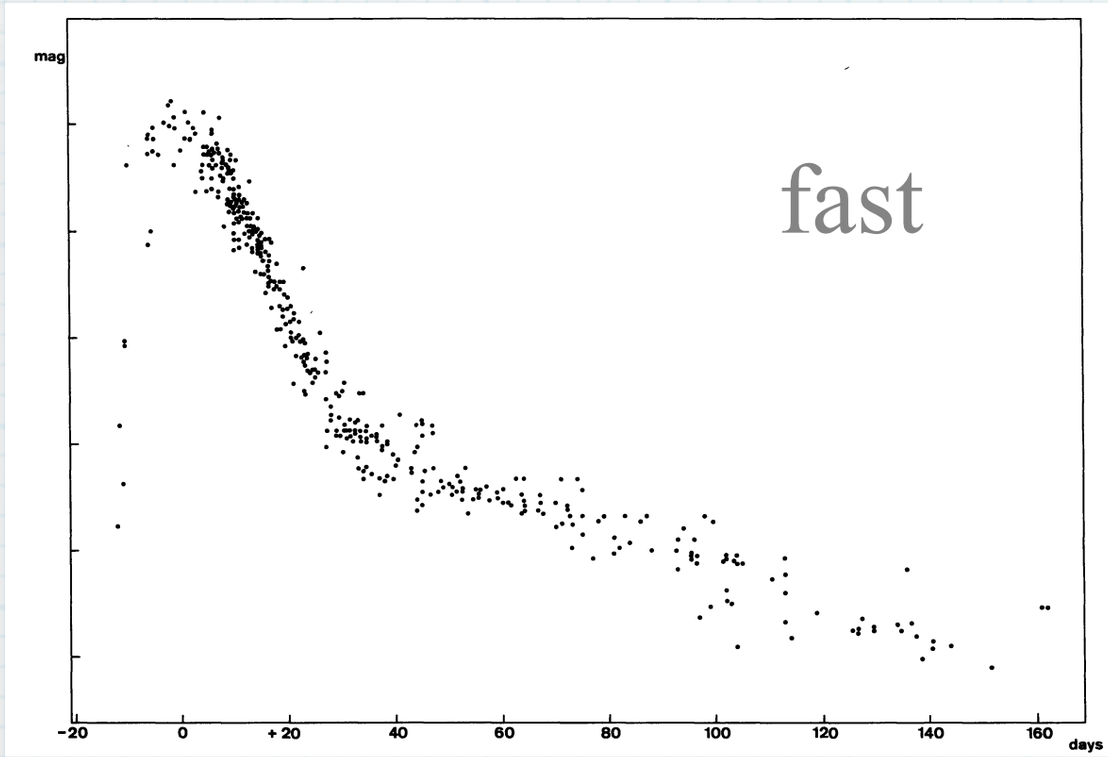
d_{L3}

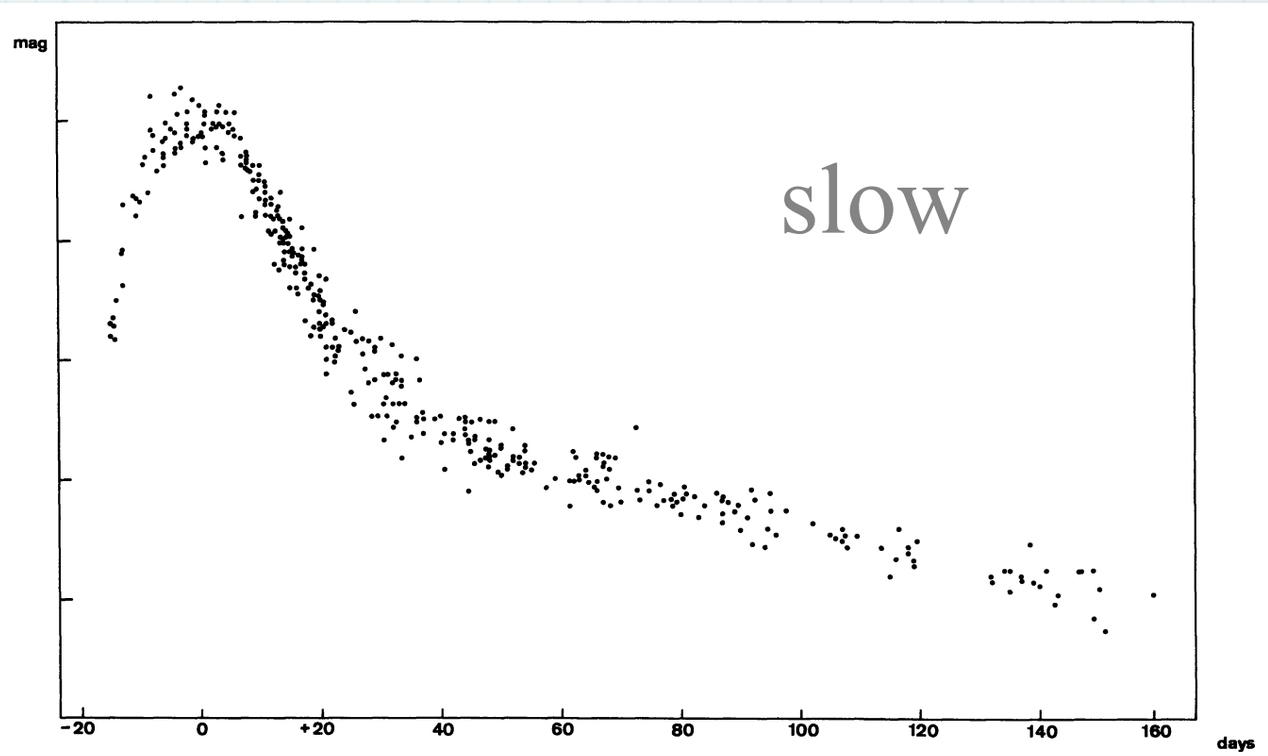


- bright! ($M \sim -19.5$ mag; $L \sim 10^{43}$ erg/s)
- occur in all types of galaxies.

SN Ia are not exactly standard candles

- Realized in the 1960s that SN Ia light curves are **nearly uniform** (Zwicky 1965; Pskovskii 1967; Kowal 1968).
- But quantitative differences have been found (Pskovskii 1970, 1977) and that there are **"fast" and "slow" decliners** (Barbon et al. 1973).





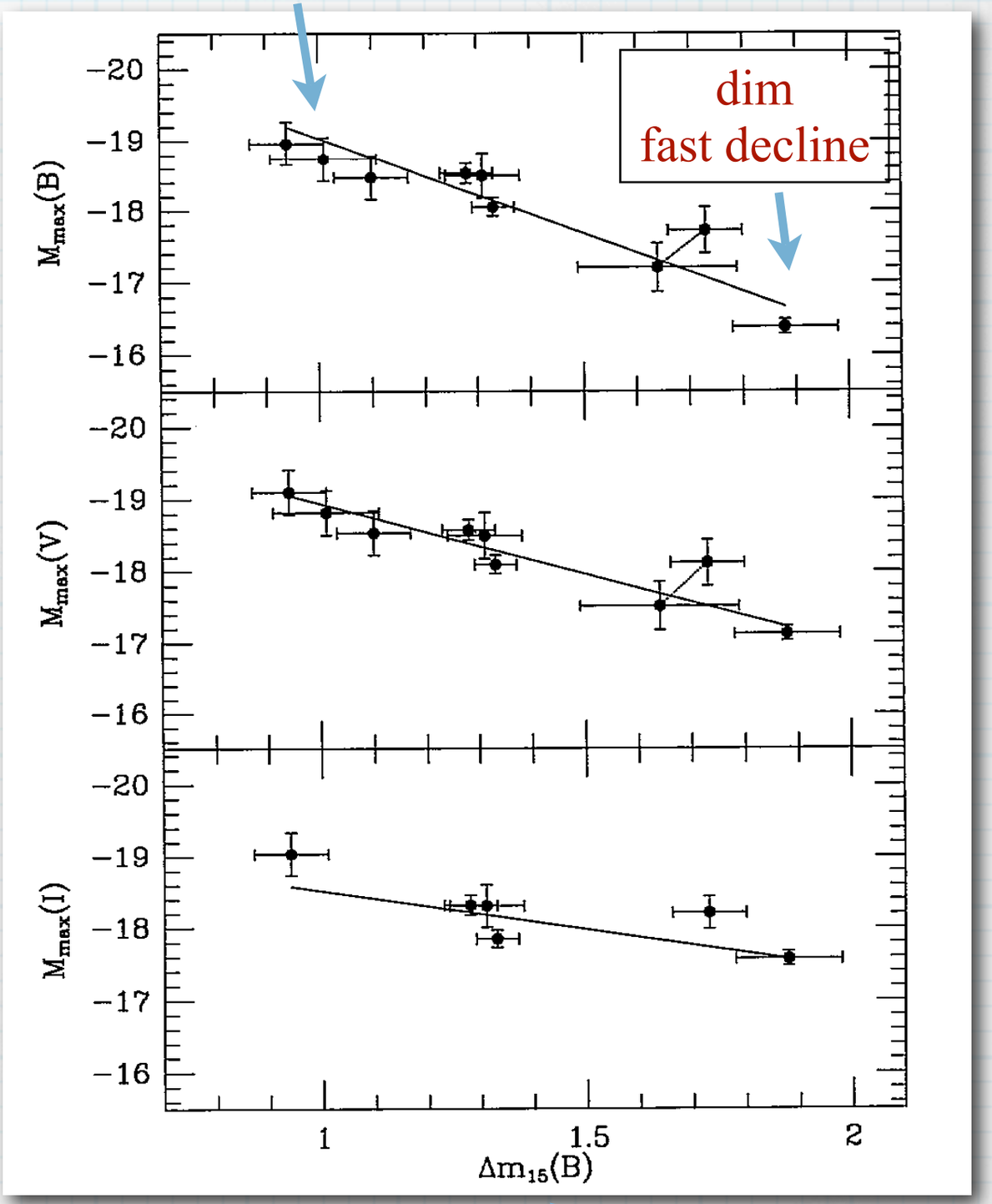
- The **Phillips relation**
- Peak absolute magnitude vs decline rate parameter are related.
- Dispersion:
  - ~0.3 - 0.4 mag in *BVI*

→ ~15 − 20% in distance

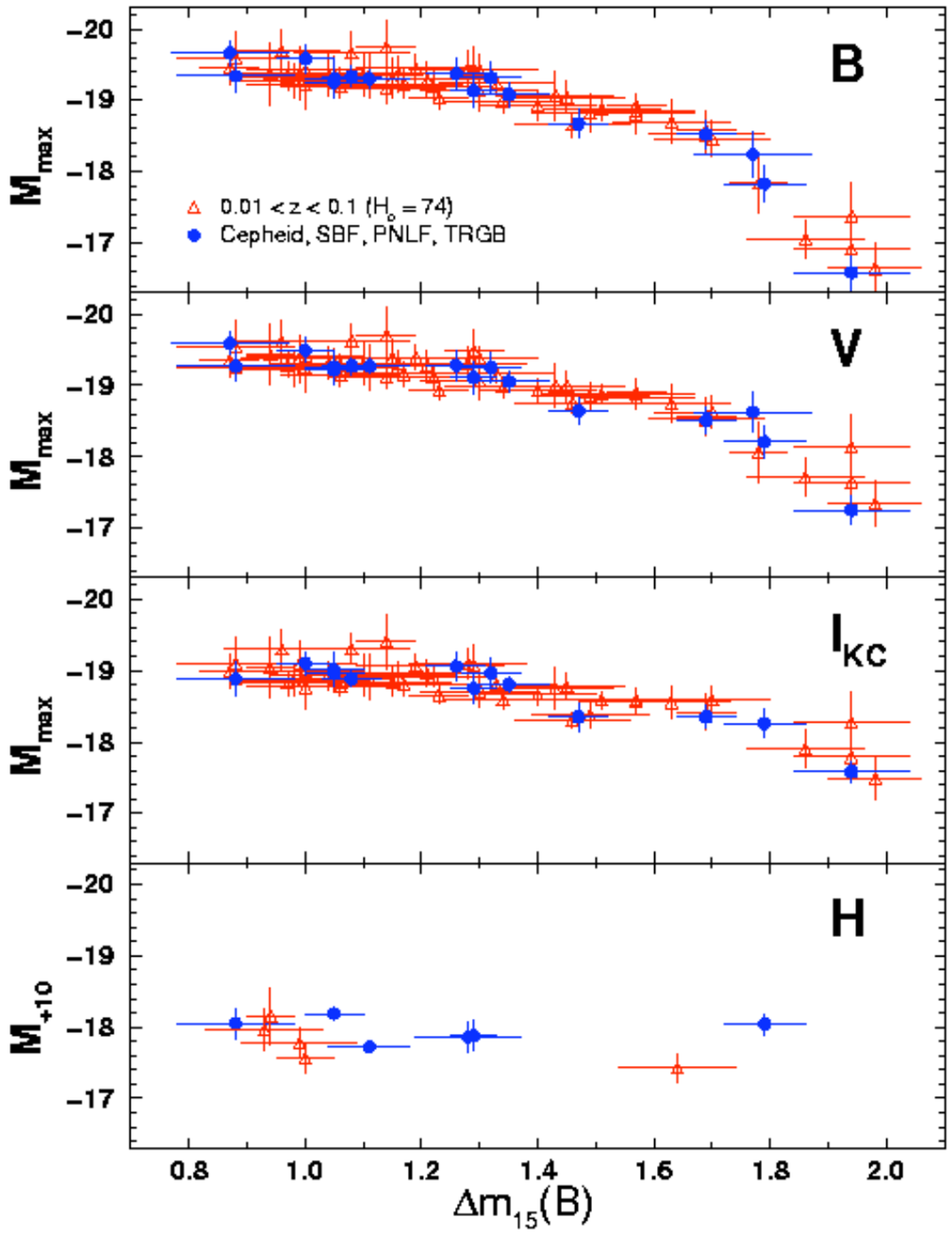
luminous
slow decline

dim
fast decline

Phillips (1993)

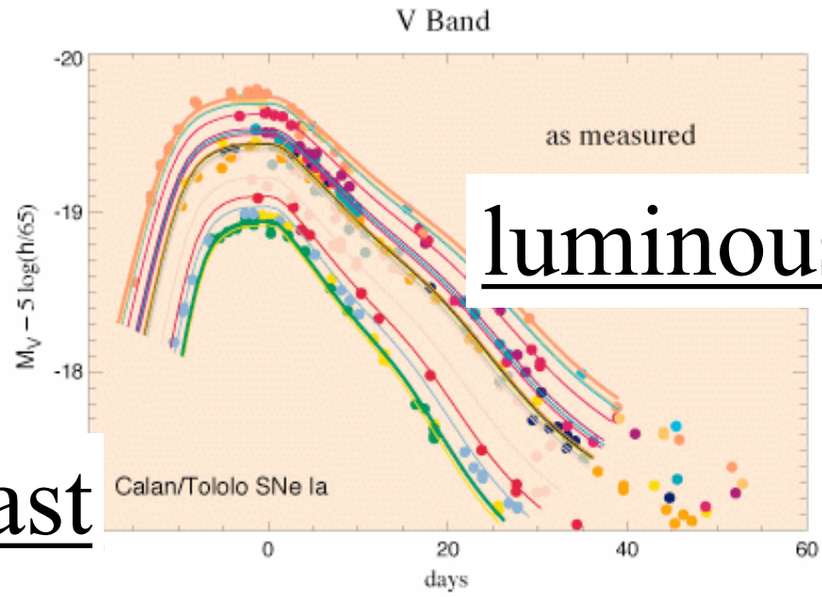


amount of dimming in 15 days
after peak in B band.

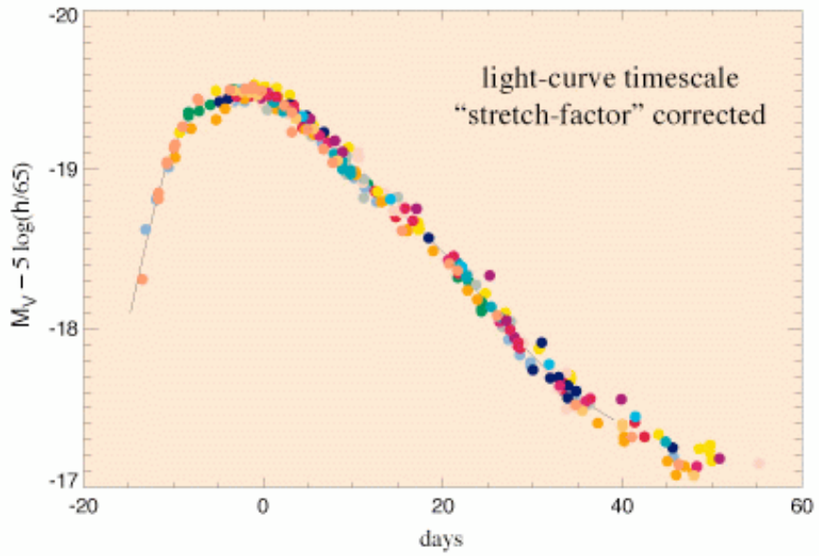


dim/fast

Low Redshift Type Ia Template Lightcurves



luminous/slow



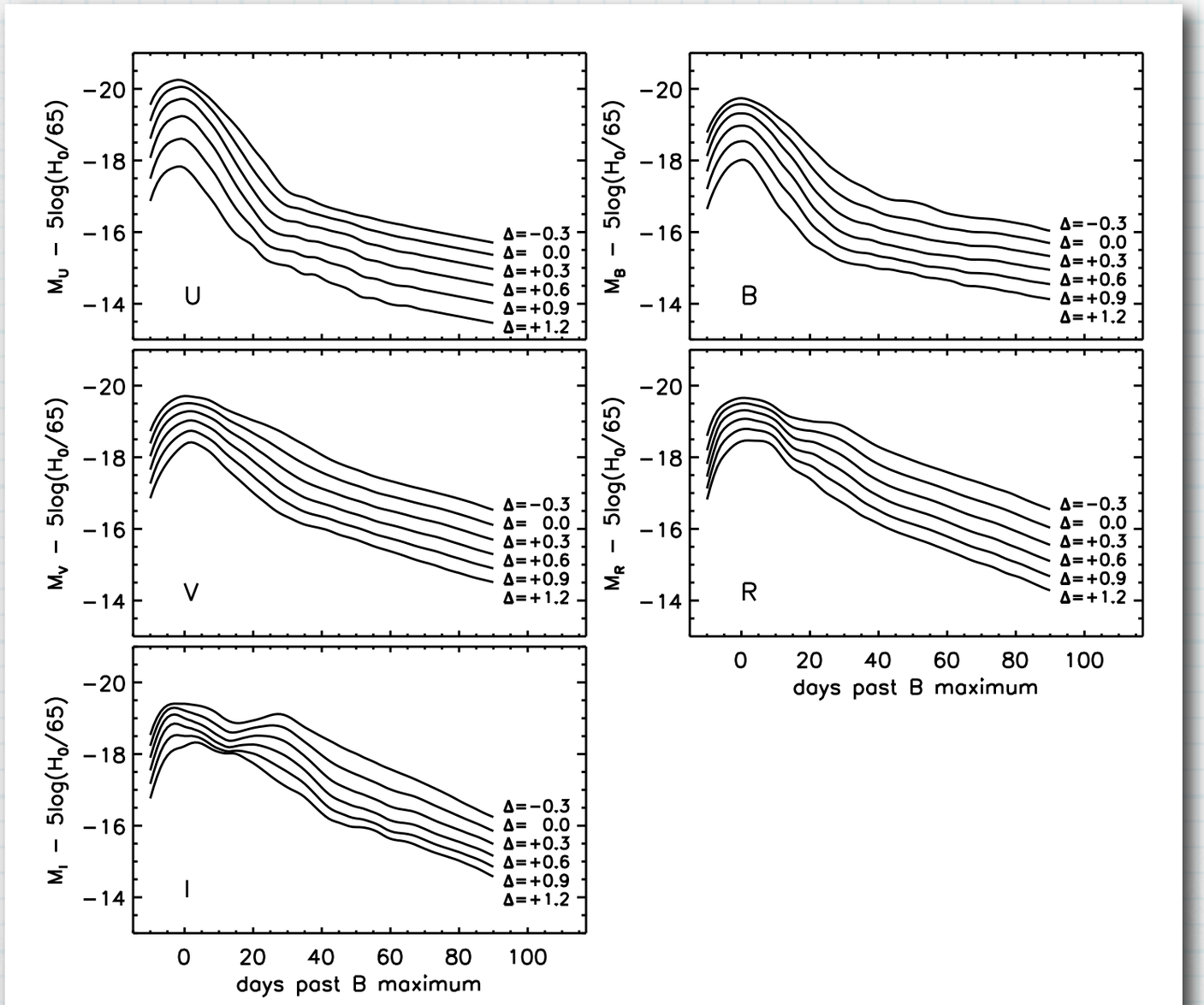
light curve width → luminosity

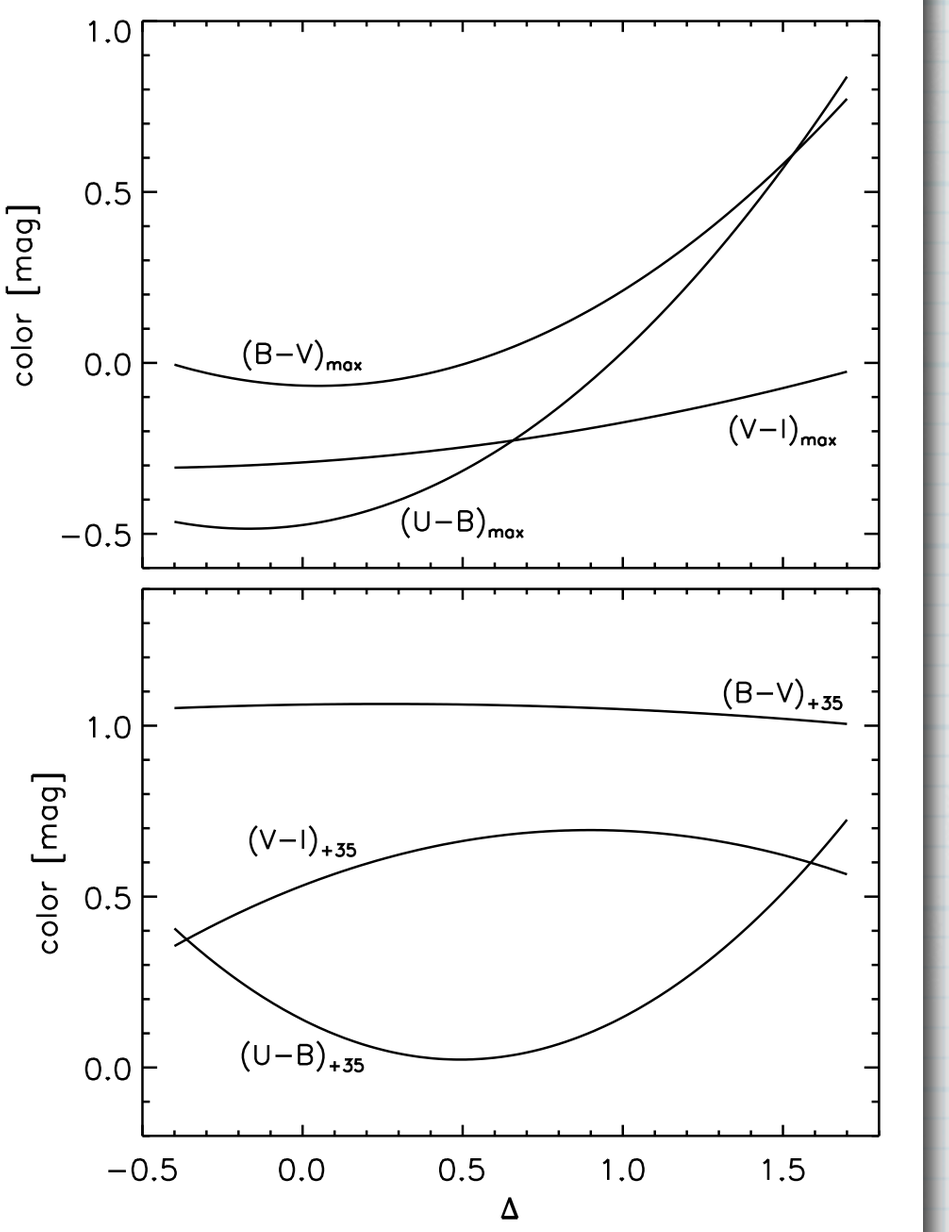
Kevin Krisciunas
http://www.nd.edu/~kkrisciu/supernovae.html

Multi-color light curve shape (**MLCS**)

Jha, Riess, & Kirshner (2006)

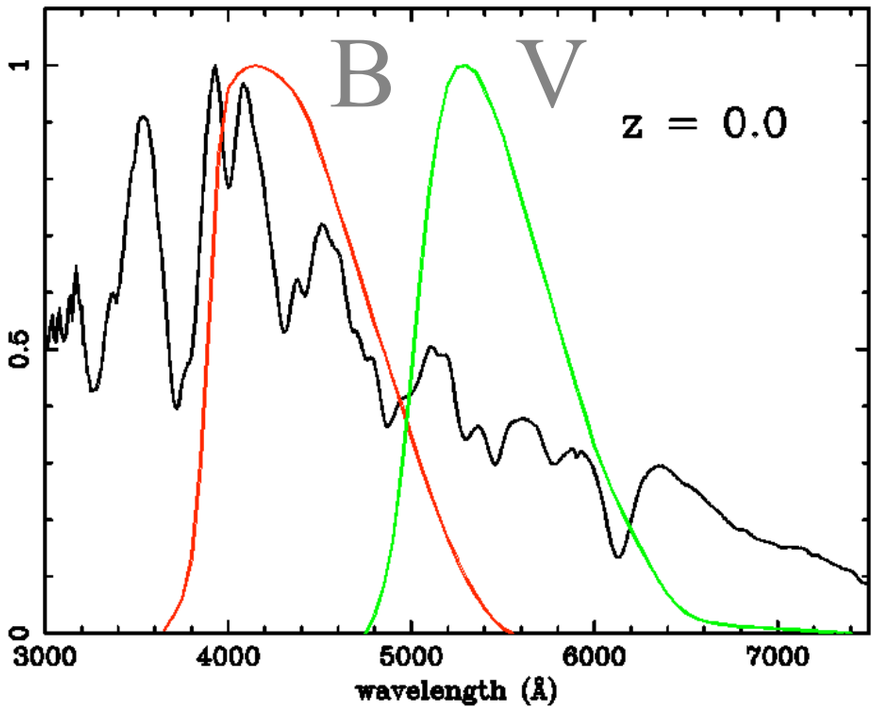
luminous/blue dim/red

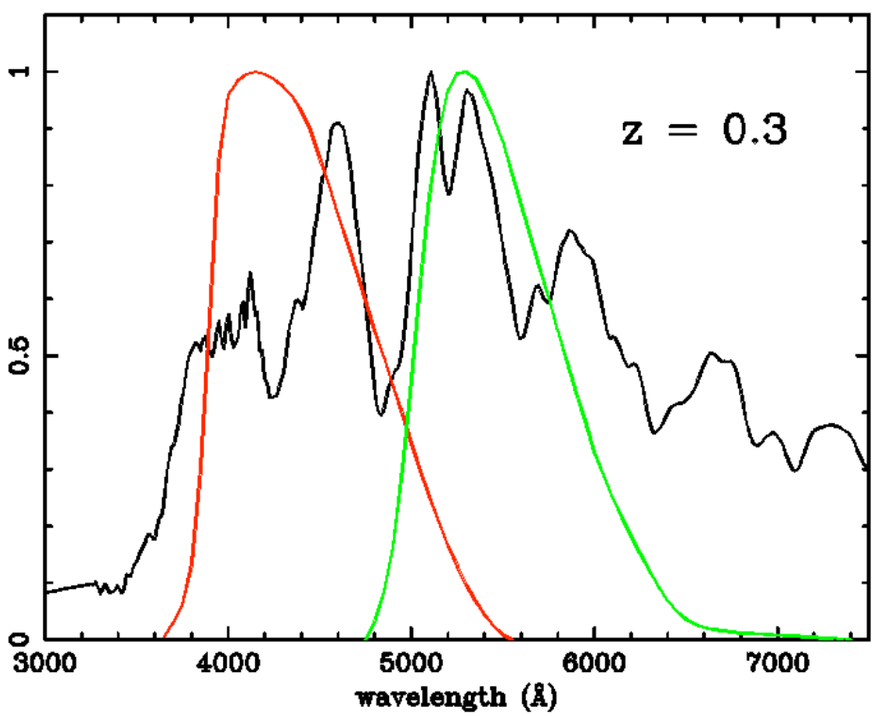




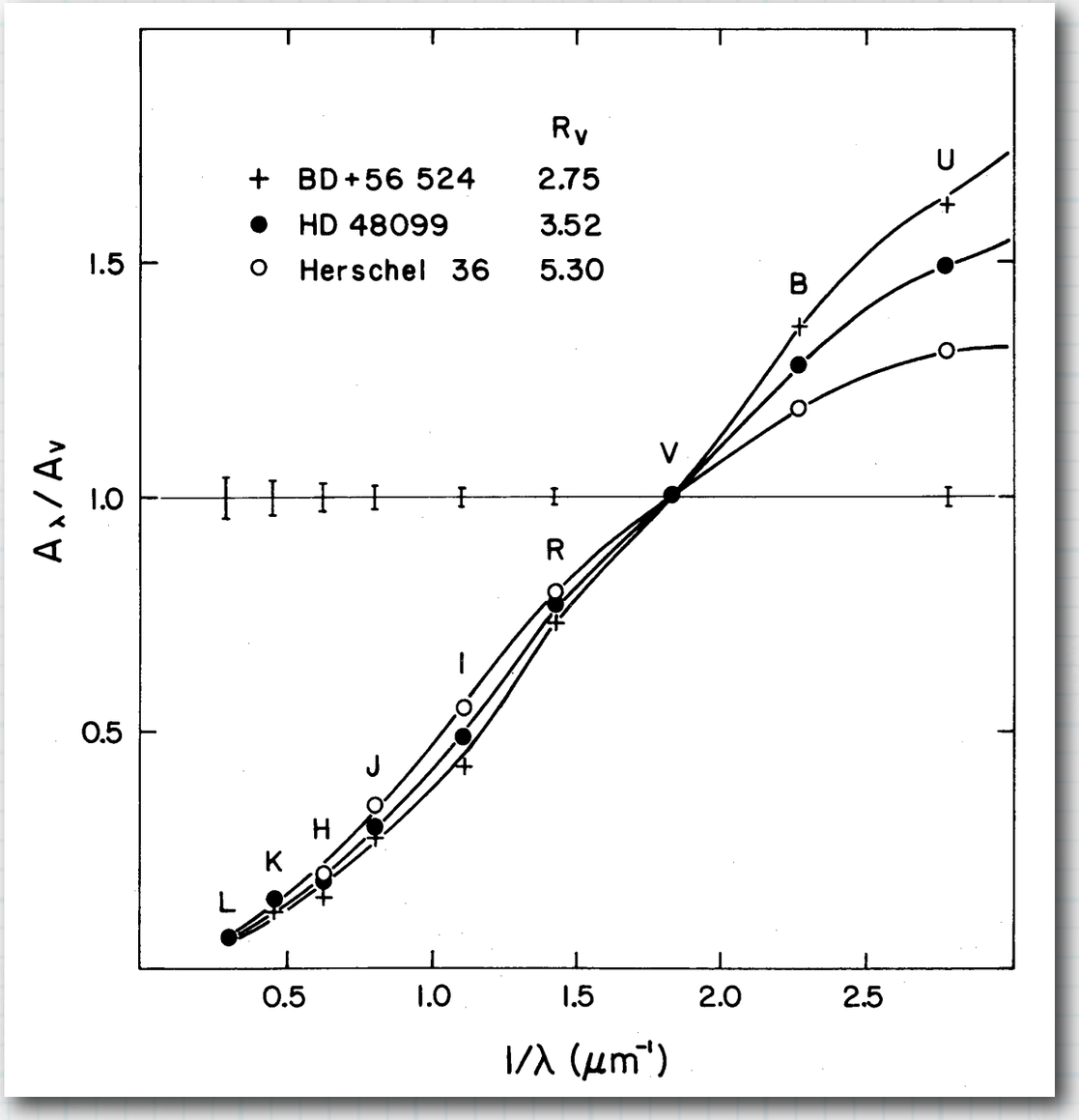
133 SN Ia; σ ~ 0.18 mag (~7% in distance!)

* **<u>Luminosity calibration</u>** (aka “training”) is done using <u>low-z SN Ia</u>.
  * need external calibrator (e.g, Cepheid variables) to determine luminosity
* High-z sources are <u>redshifted</u>. Must correct observed light curves into rest-frame.
* **<u>K-correction</u>**: requires assumption of *spectrum and its time dependence*.





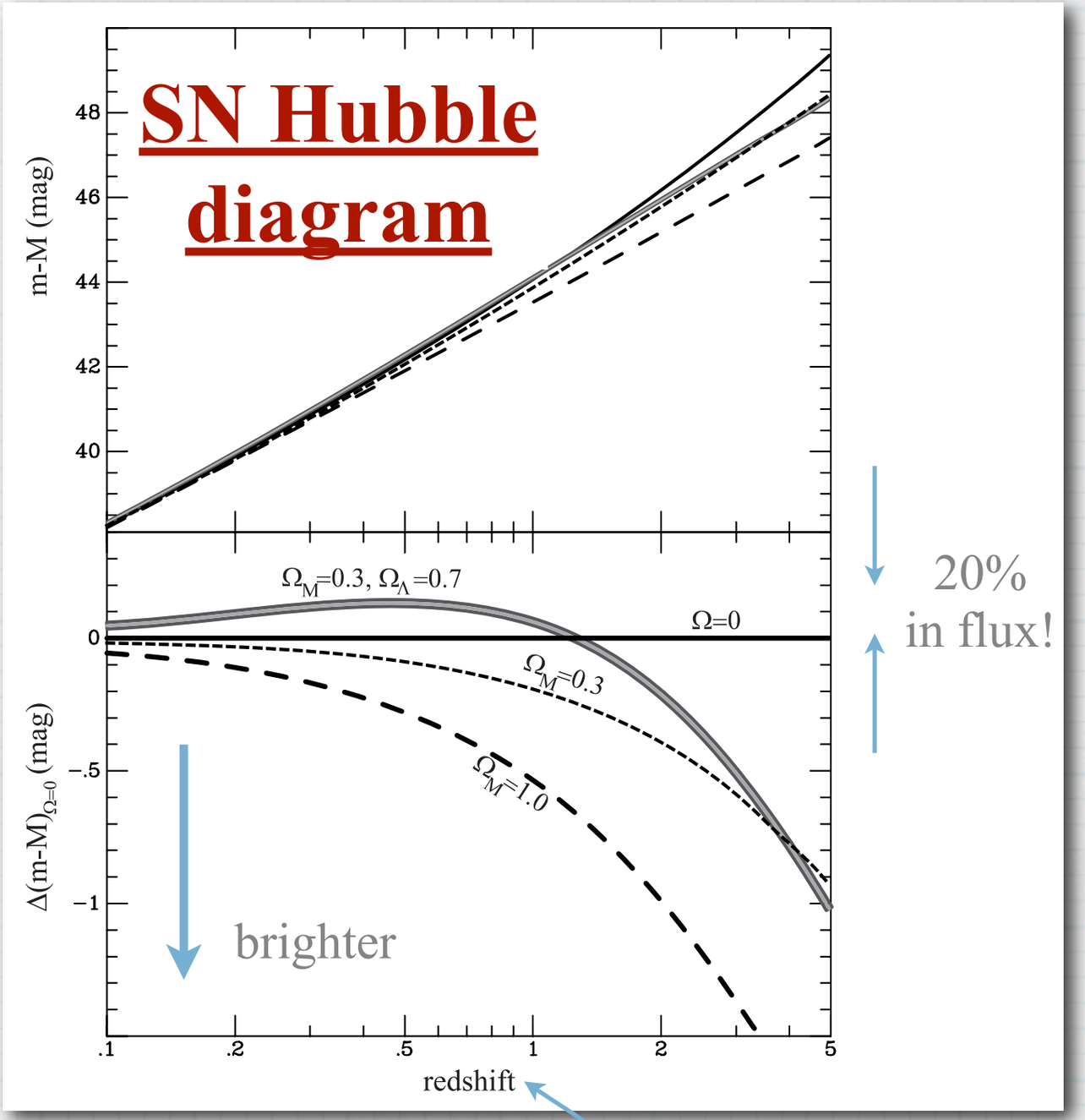
* **Reddening and extinction** by dust in our Galaxy and in the SN host galaxy.
* Results in dimming of SN.
* Reddening/extinction relation depends on properties of dust.
  * evolution with redshift?



Cardelli, Clayton, & Mathis (1989)

- SNe can be:
  - standardized
  - observed out to large z.

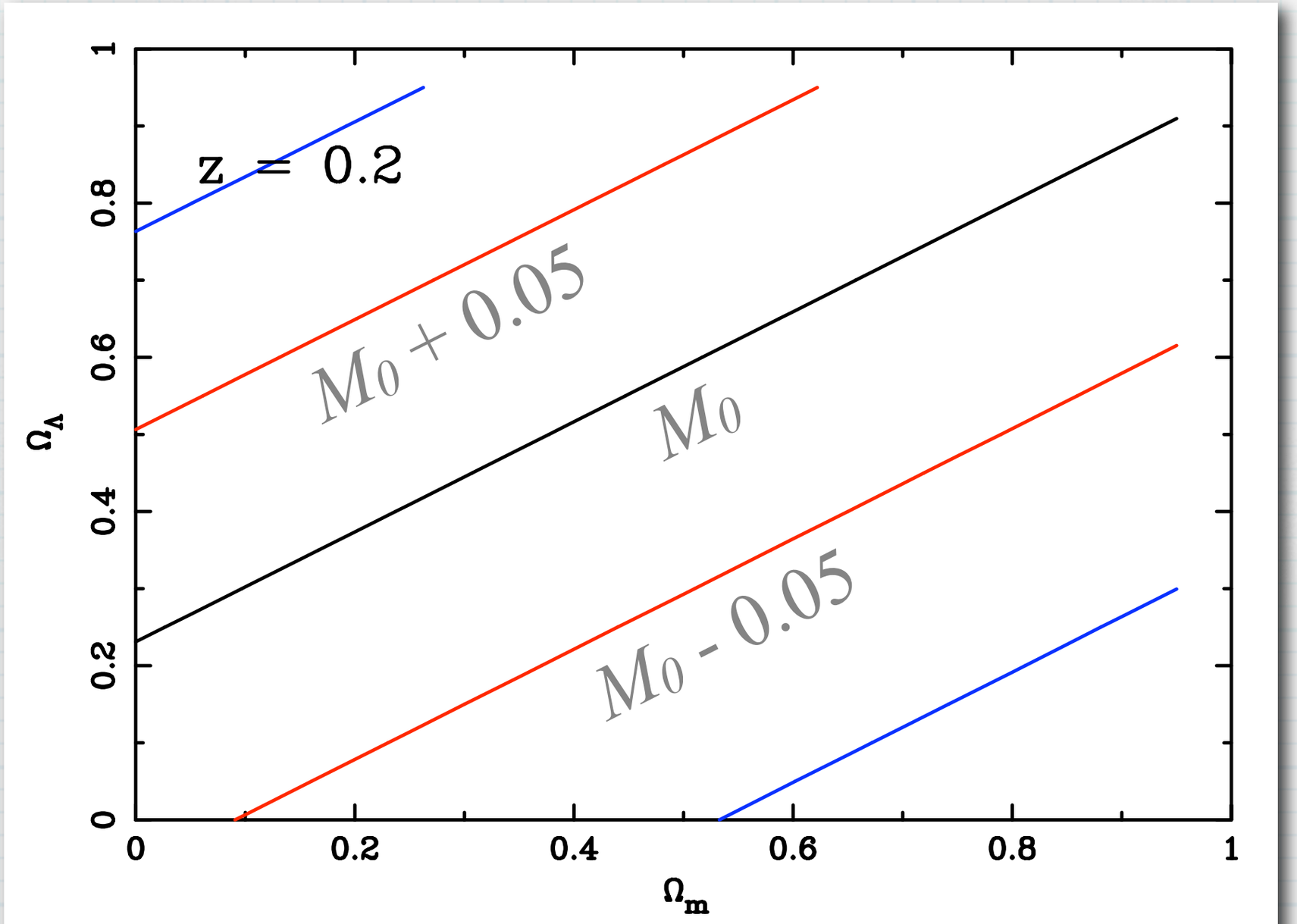
- redshift-distance $d_L(z)$ relation tells you the expansion history, which depends on the matter and energy content of the universe



$$d_L = \frac{c}{H_0}\kappa_0^{-1/2}\, S\left(\kappa_0^{1/2}\int_0^z dz'\left[\sum_i \Omega_i(1+z')^{3+3w_i} - \kappa_0(1+z')^2\right]^{-1/2}\right)$$

$$S(x) = \sin(x), x, \sinh(x) \text{ for closed, flat, open} \qquad \kappa_0 = \sum_i \Omega_i - 1$$

- Distance measurement of a single SN *cannot* determine absolute values of Ω_m and Ω_Λ.
- Calibration errors result in wrong cosmology.



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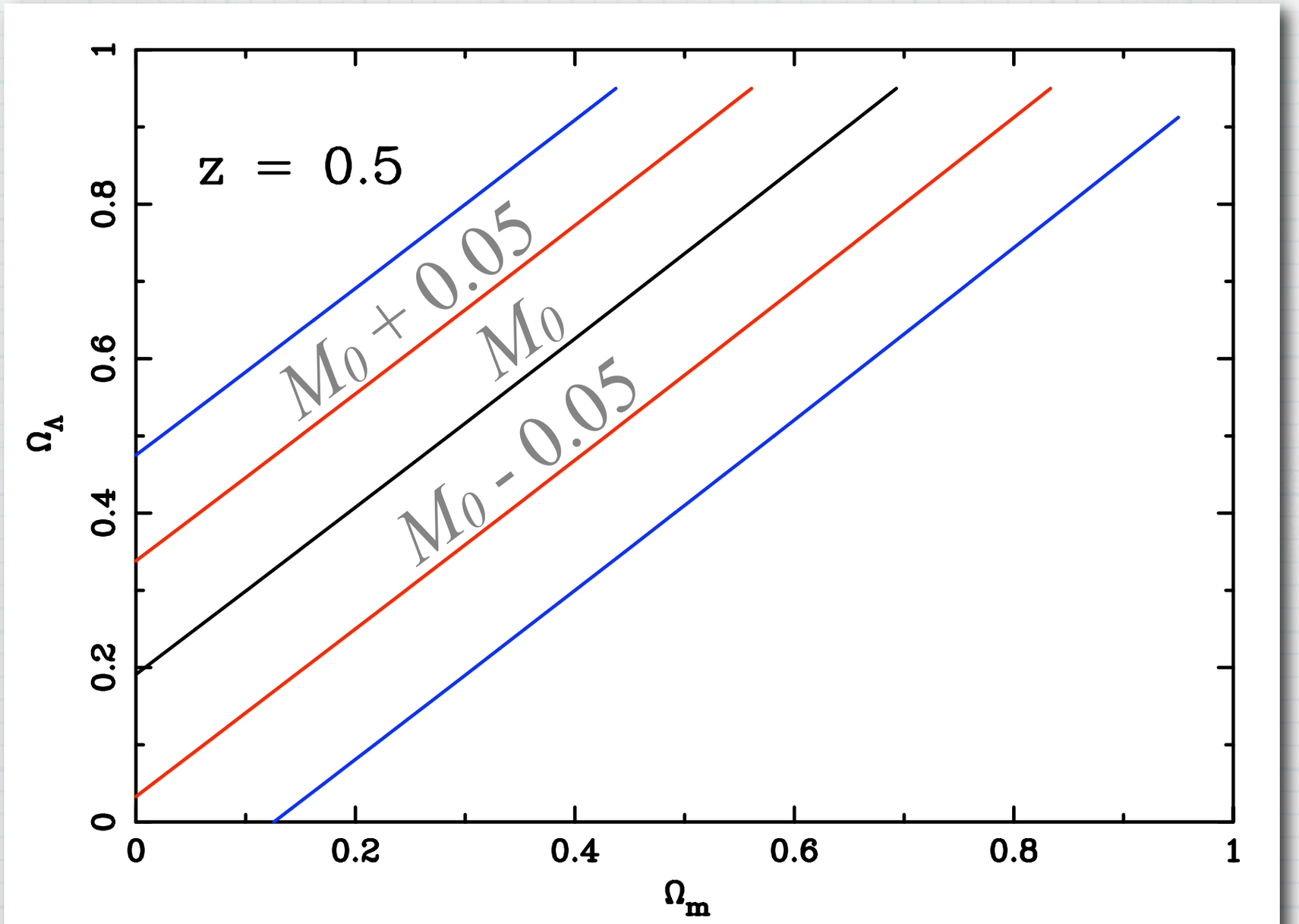

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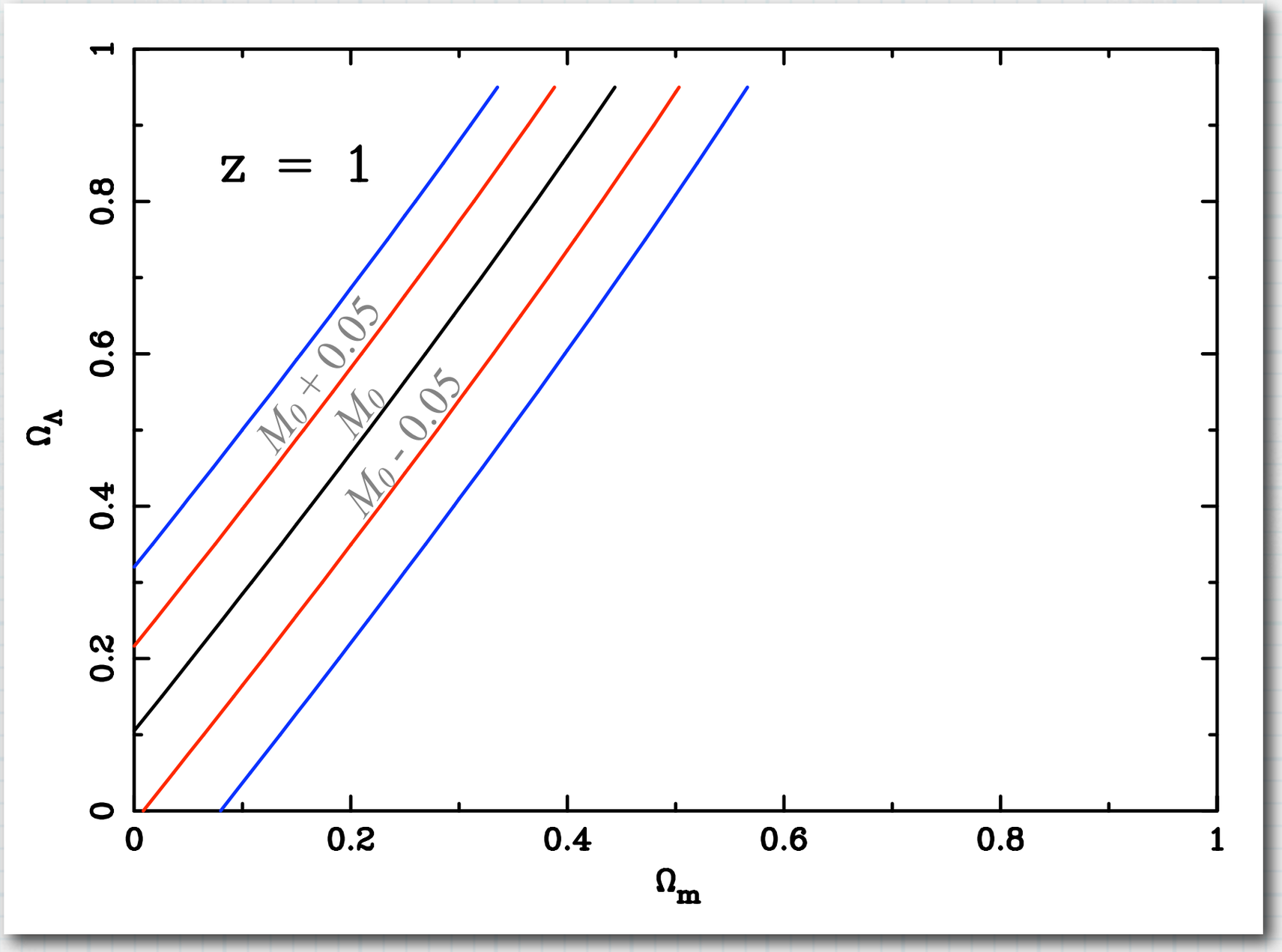
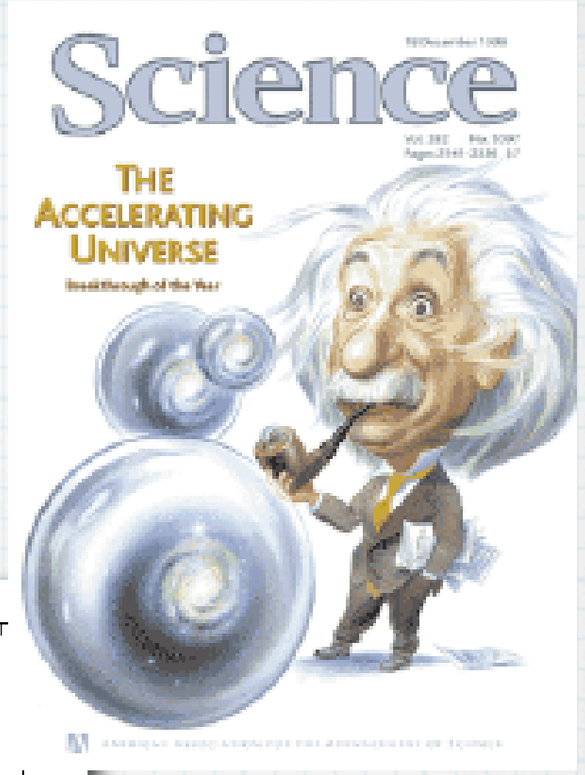
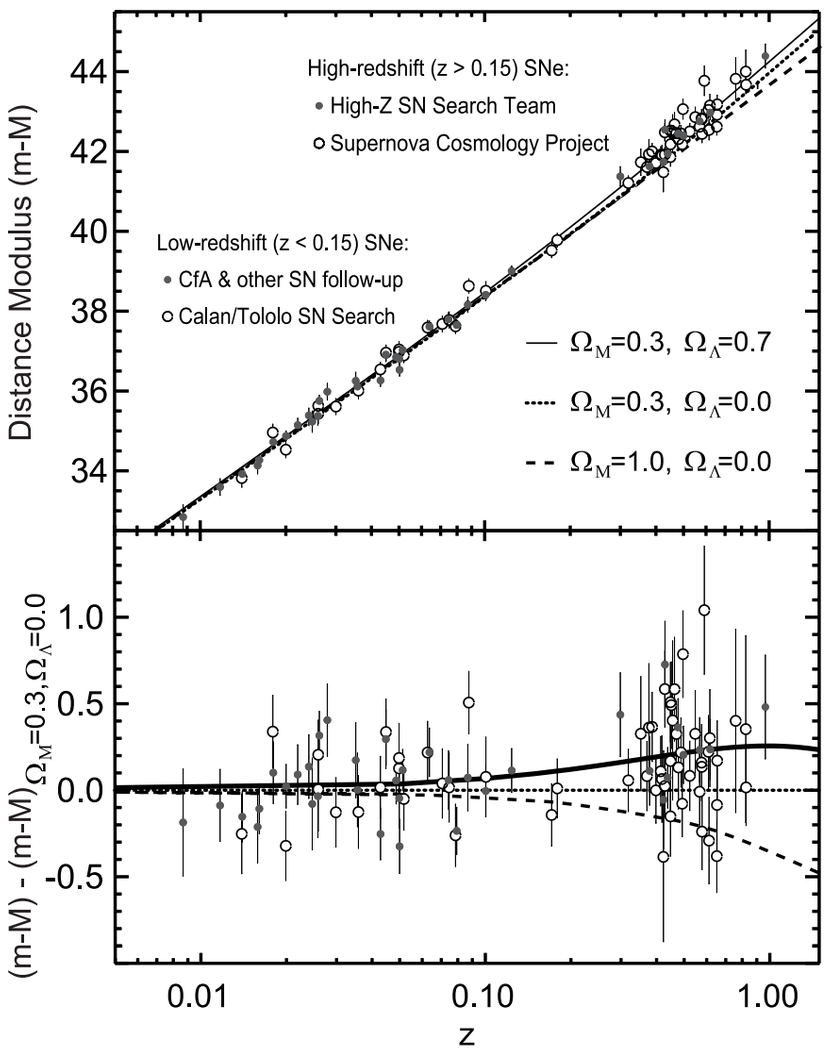


First evidence for an accelerating universe!

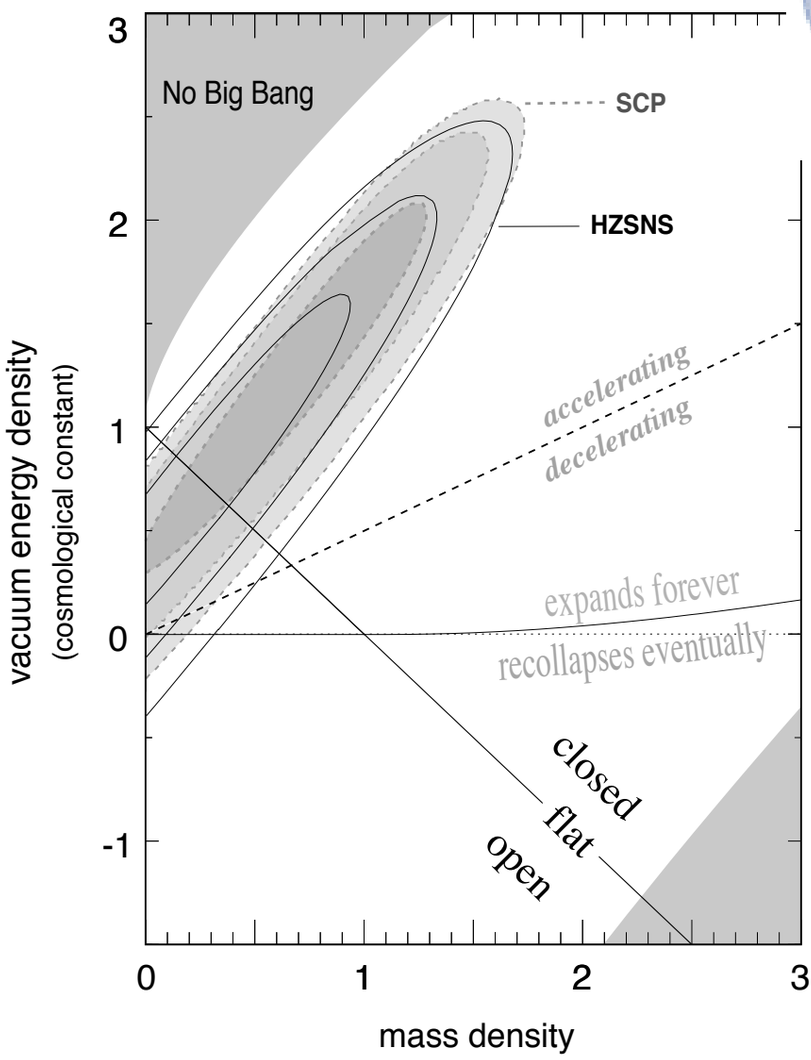
$$q_0 = \frac{\Omega_m}{2} - \Omega_\Lambda < 0 \qquad \Omega_\Lambda > \frac{\Omega_m}{2}$$



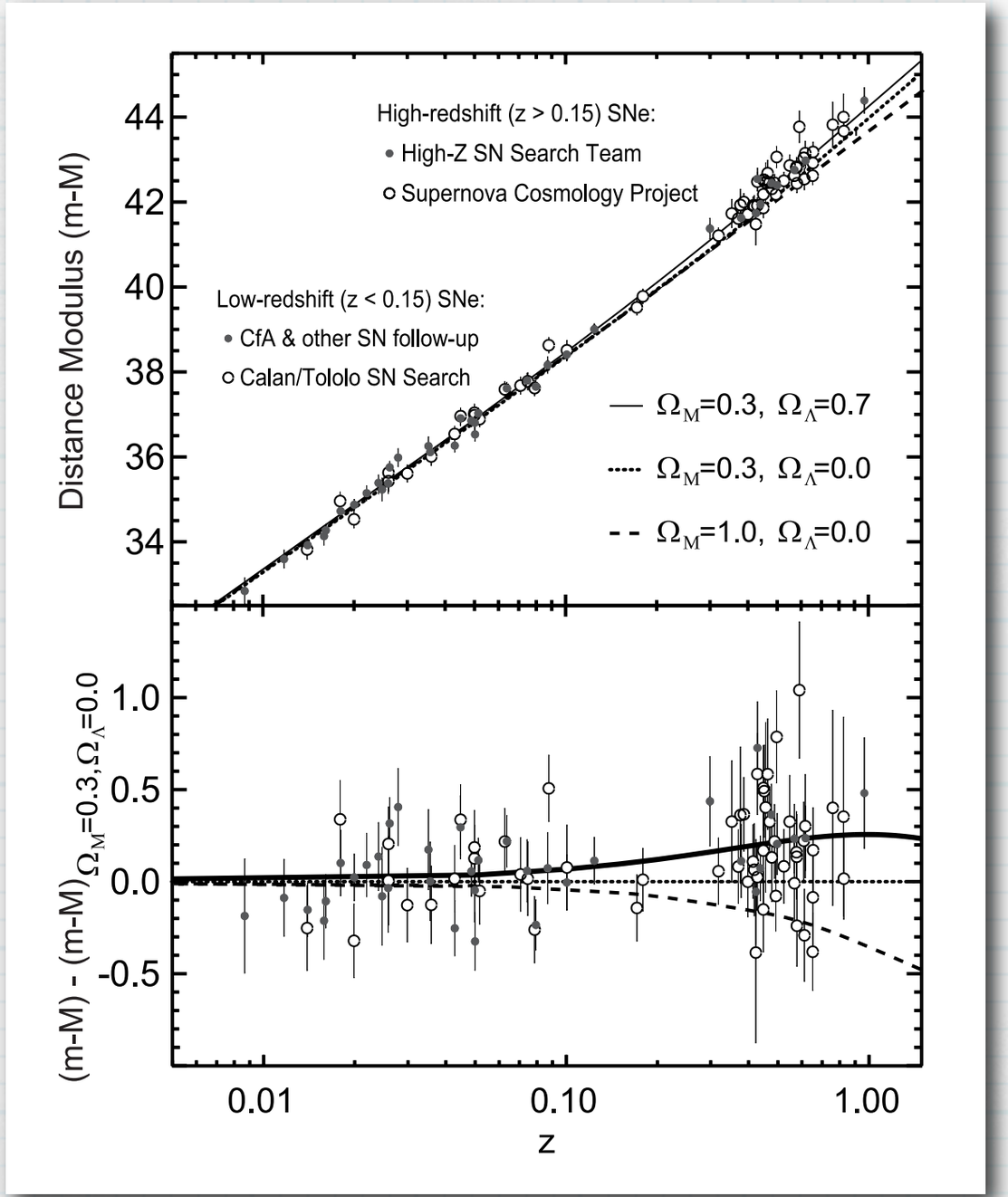
1998 Breakthrough of the Year



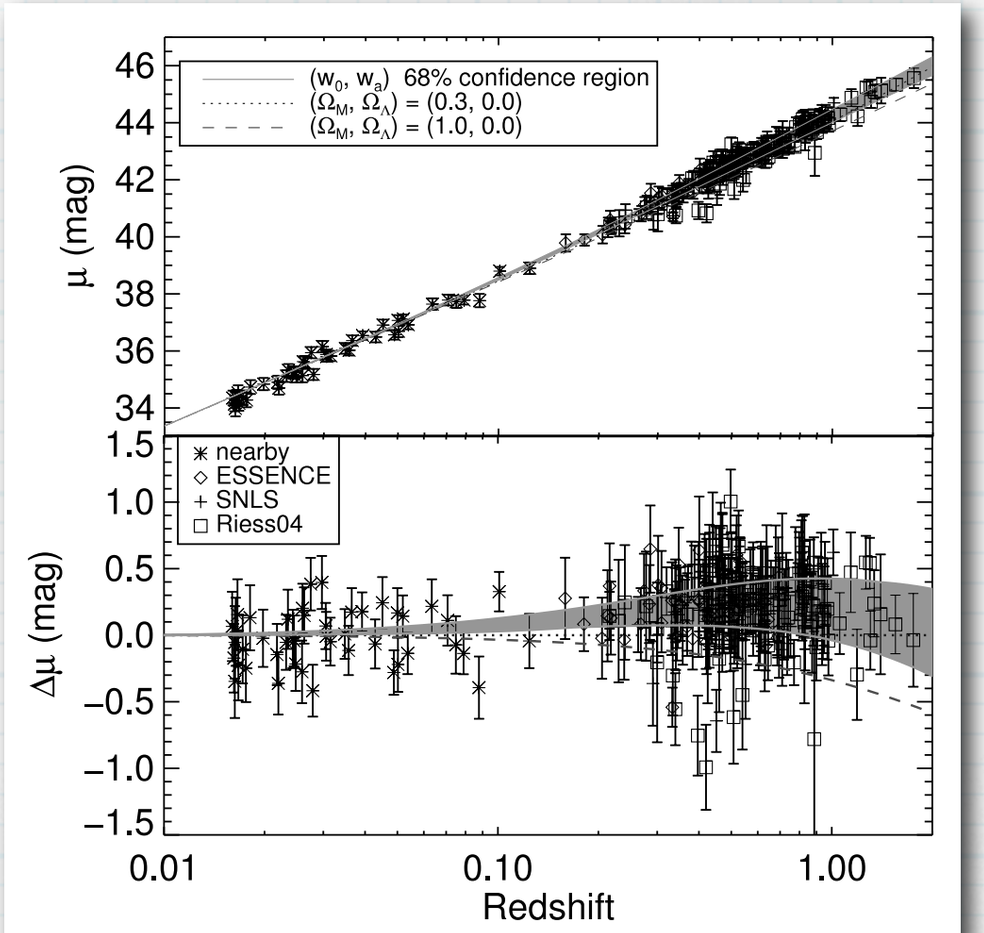
Perlmutter & Schmidt 2003

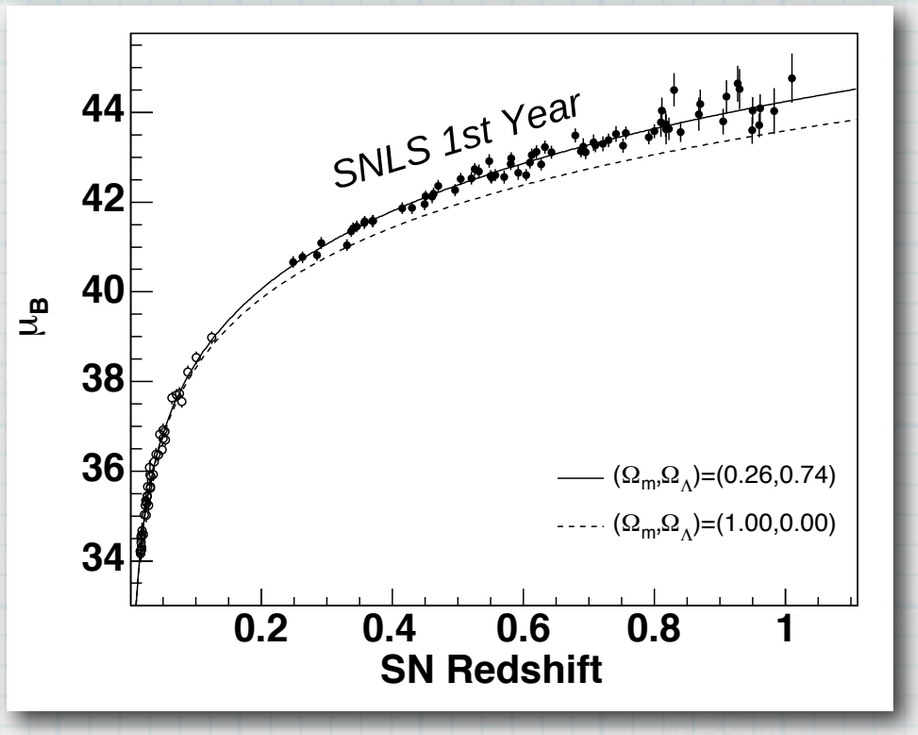


HZSNS (Riess et al. 1998) SCP (Perlmutter et al. 1999)



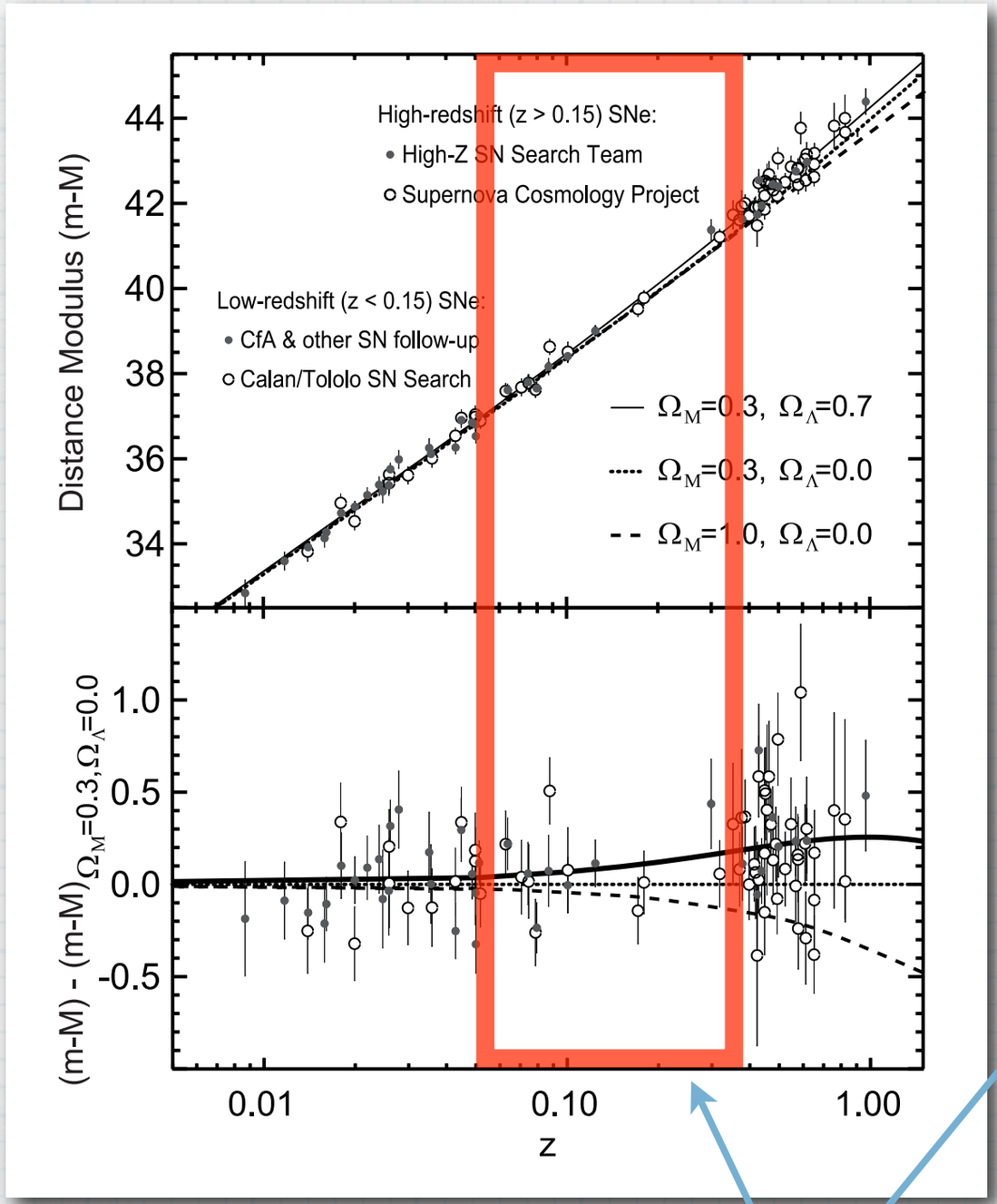
ESSENCE (Wood-Vasey et al. 2007)

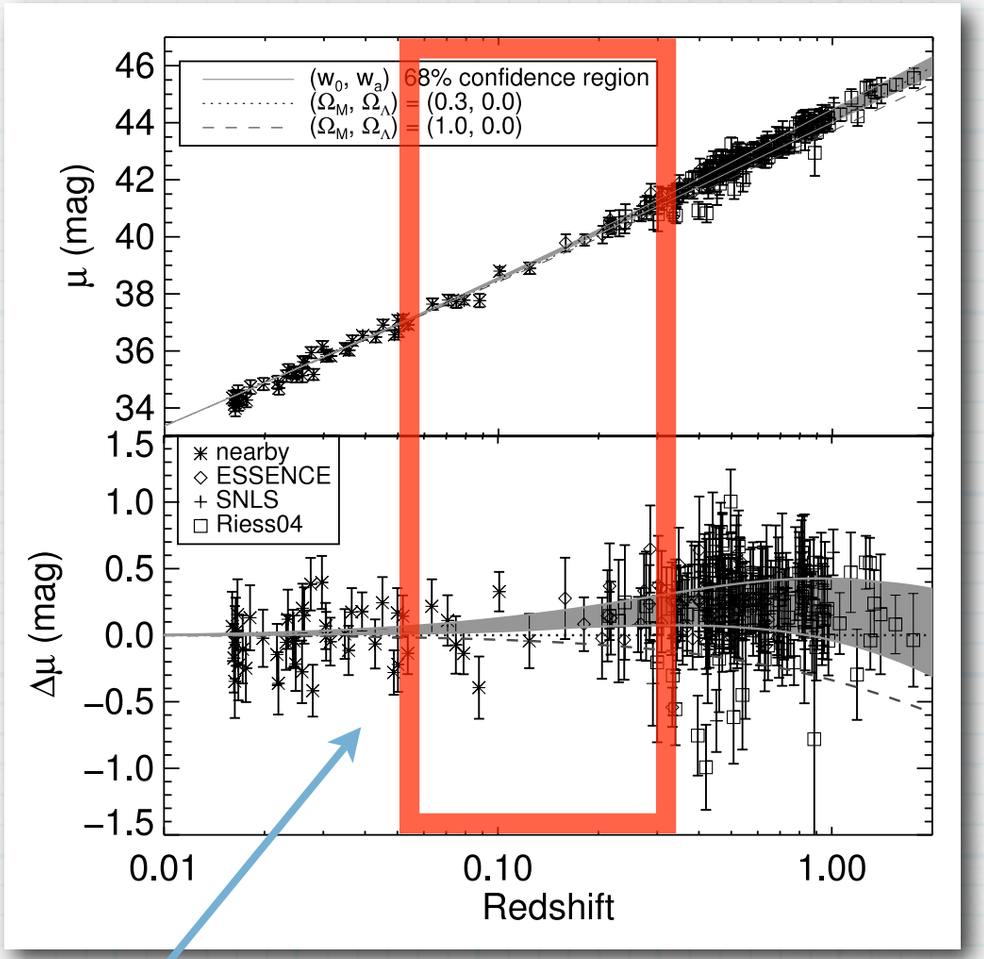


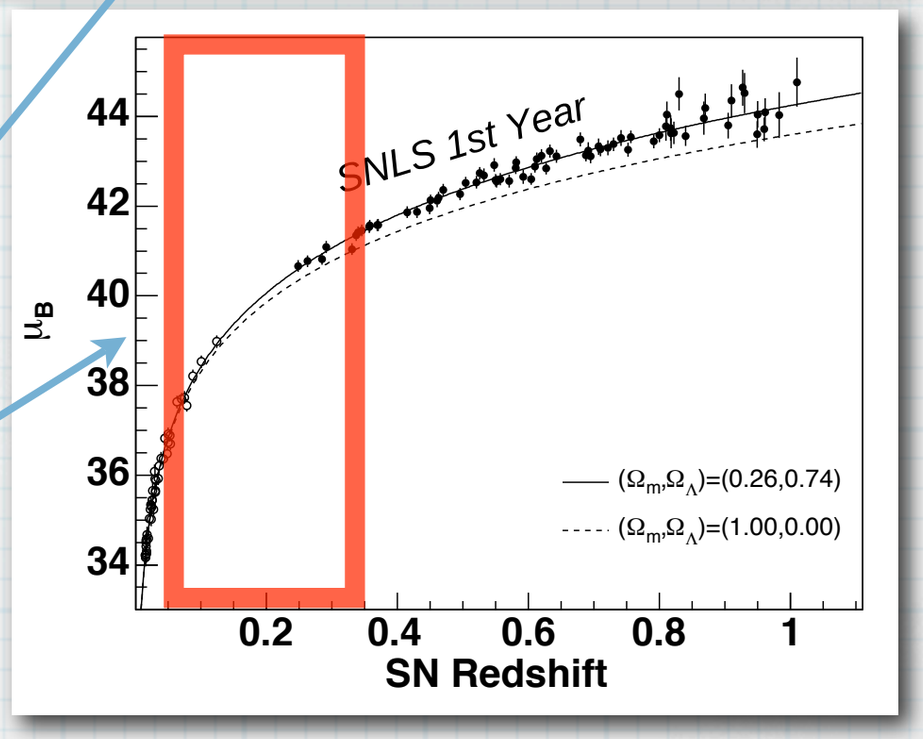


SNLS (Astier et al. 2006)

ESSENCE (Wood-Vasey et al. 2007)



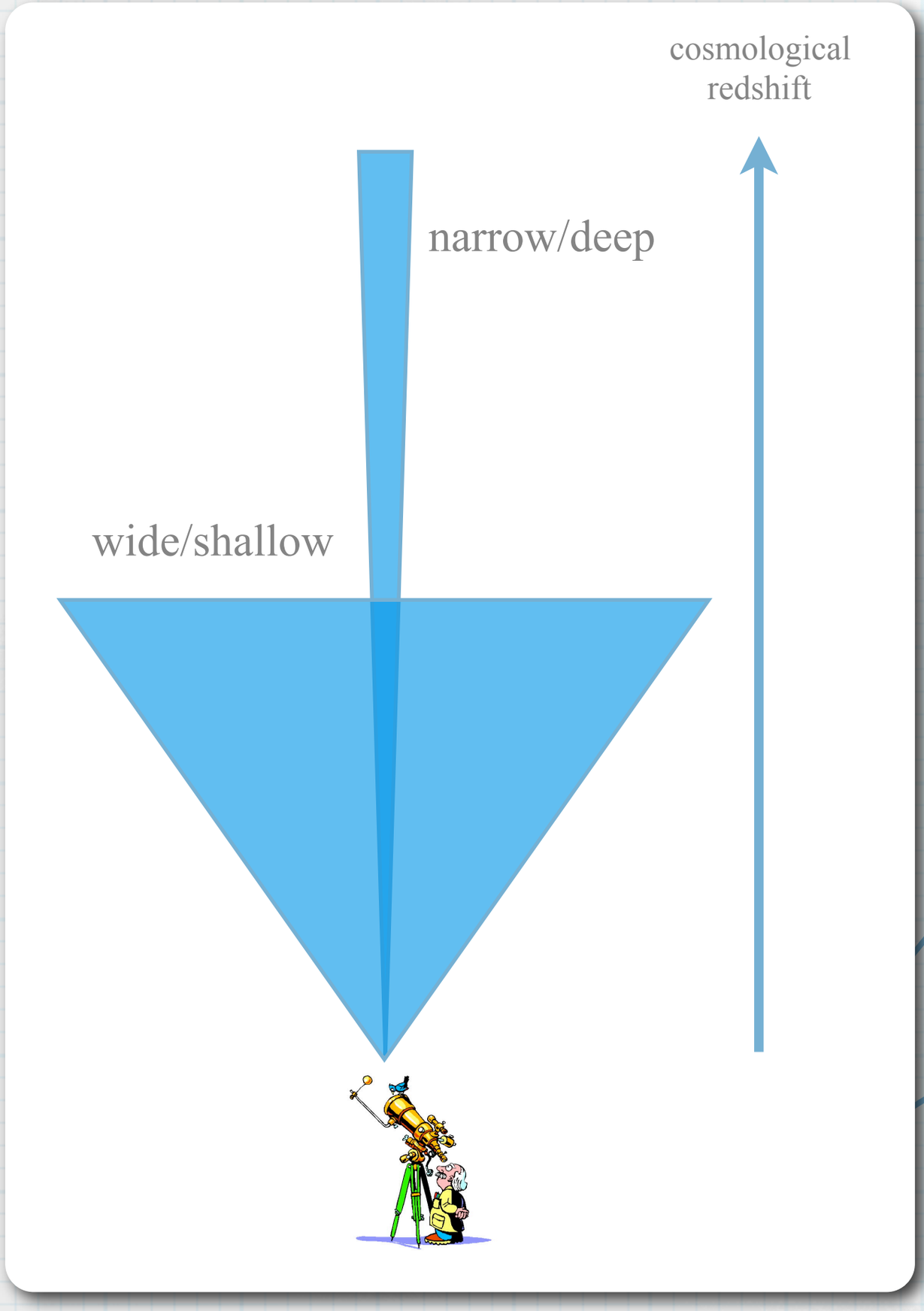


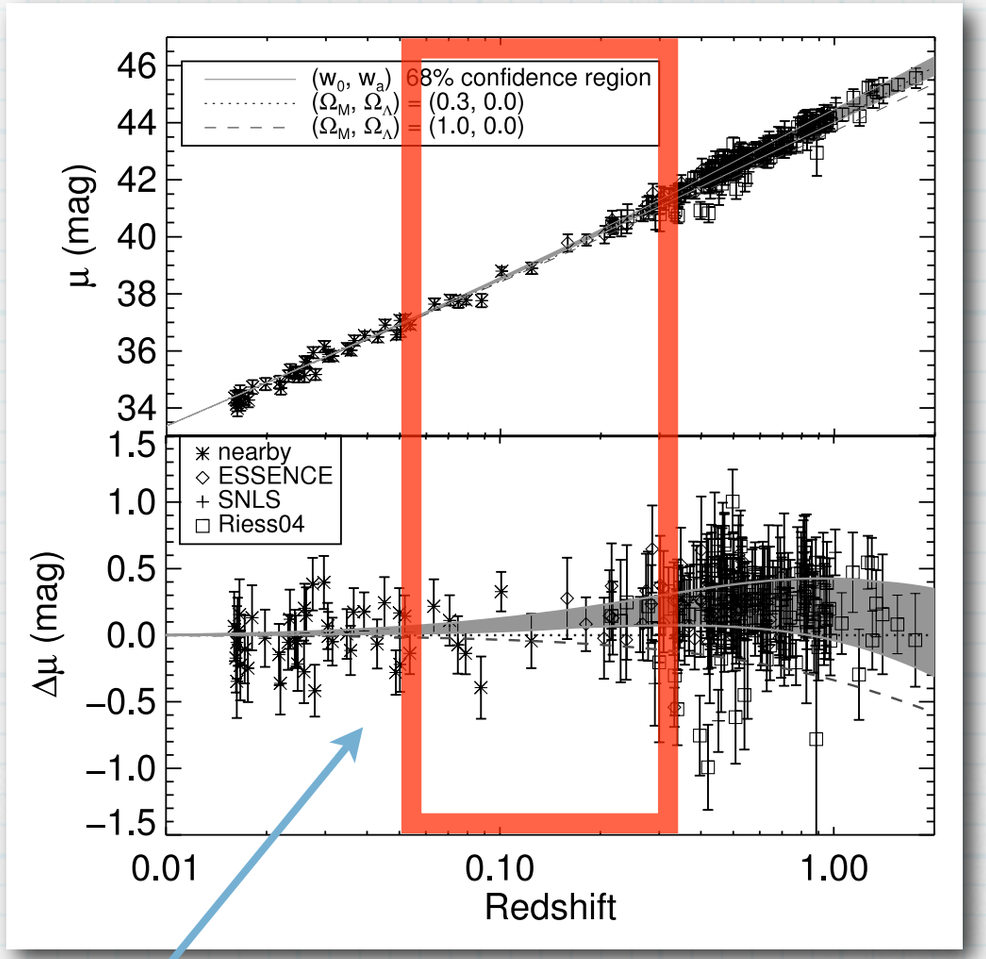


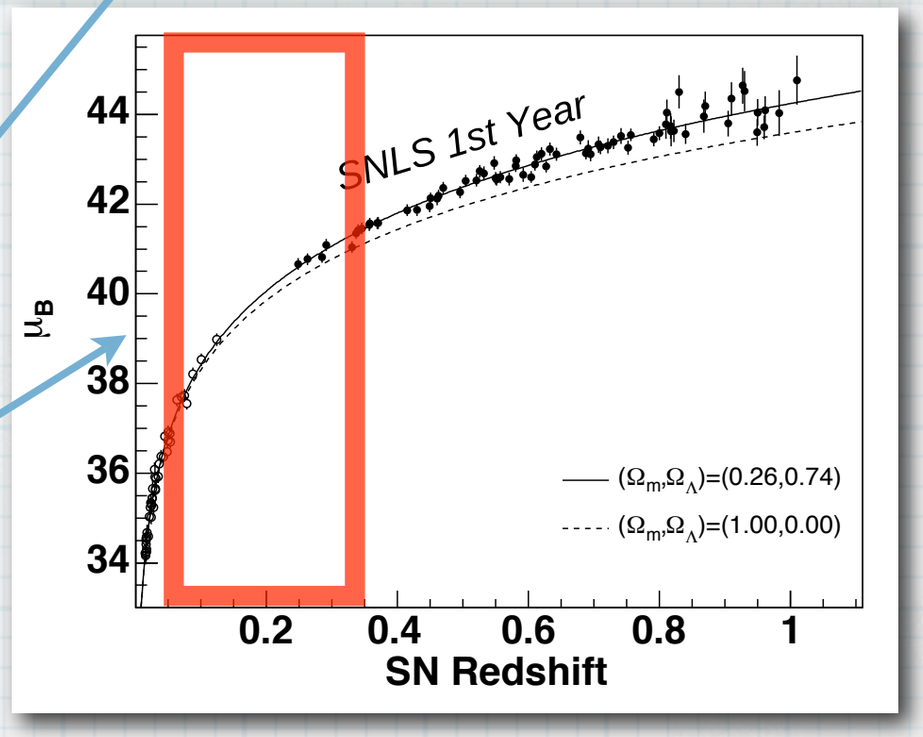
redshift desert

SNLS (Astier et al. 2006)

ESSENCE (Wood-Vasey et al. 2007)

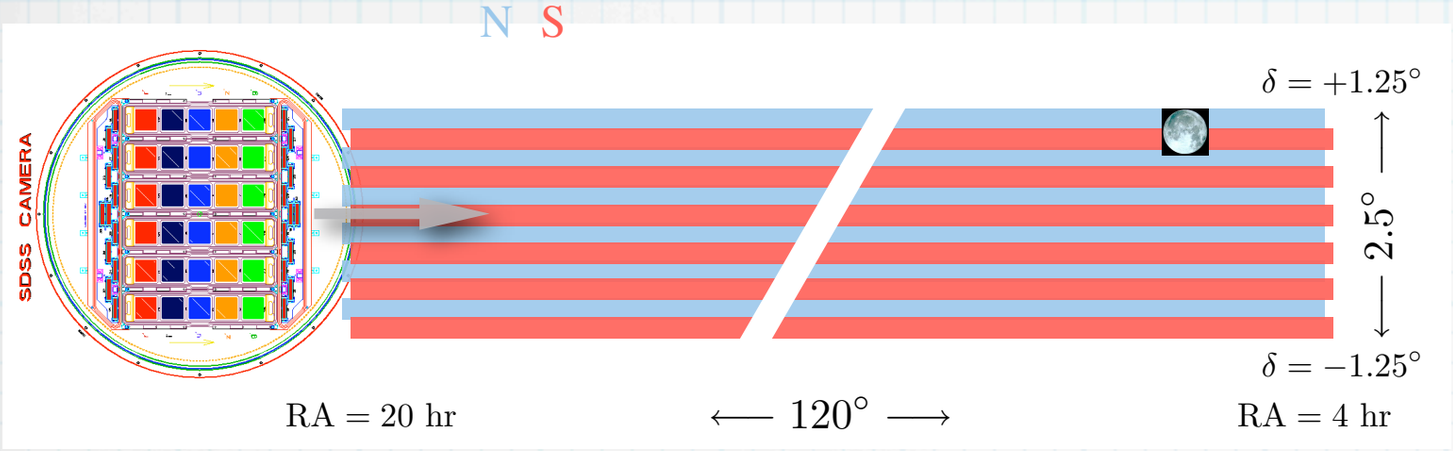


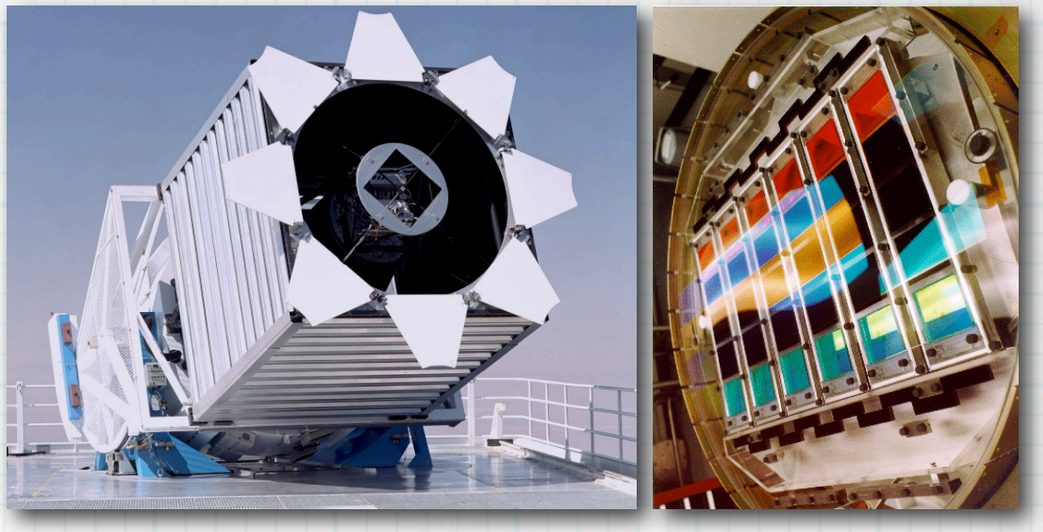




SNLS (Astier et al. 2006)

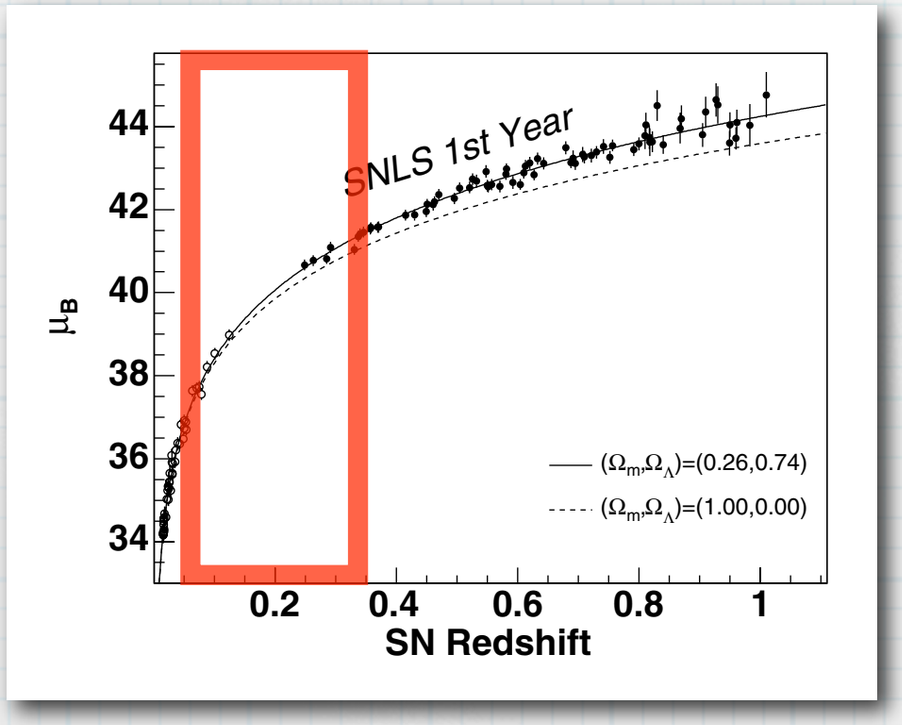
SDSS-II SN Survey





- 300 deg^2 every 2 days during Sept 1 - Nov 30 of 2005/6/7.

- multi-band light curves of SN Ia at $0.05 < z < 0.4$ (redshift desert)



SNLS (Astier et al. 2006)

- shallow-wide survey; probes ~8 times more total volume than SNLS

- well-calibrated photometric system (~1% absolute flux)

- redshift range allows self-trained cosmology analysis *on a single telescope*

http://sdssdp47.fnal.gov/sdsssn/sdsssn.html

SDSS-II SN Survey Team

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Subaru team	Y. Ihara
KPNO team	M. Florack, A. Hirschauer, D. O'Connor
Keck team	R. Foley, A. Filippenko

Data Processing Challenges

- A "good" full night of imaging results in:
  - ~200 GB of reduced images
    - *gri* frames run through an image subtraction program on dedicated cluster at APO
      - register images, match PSF, zeropoint scaling, etc.
    - search for statistically significant deviations
    - dump known variables, moving objects
    - *must* be done within 24 hours!

add fake SNe

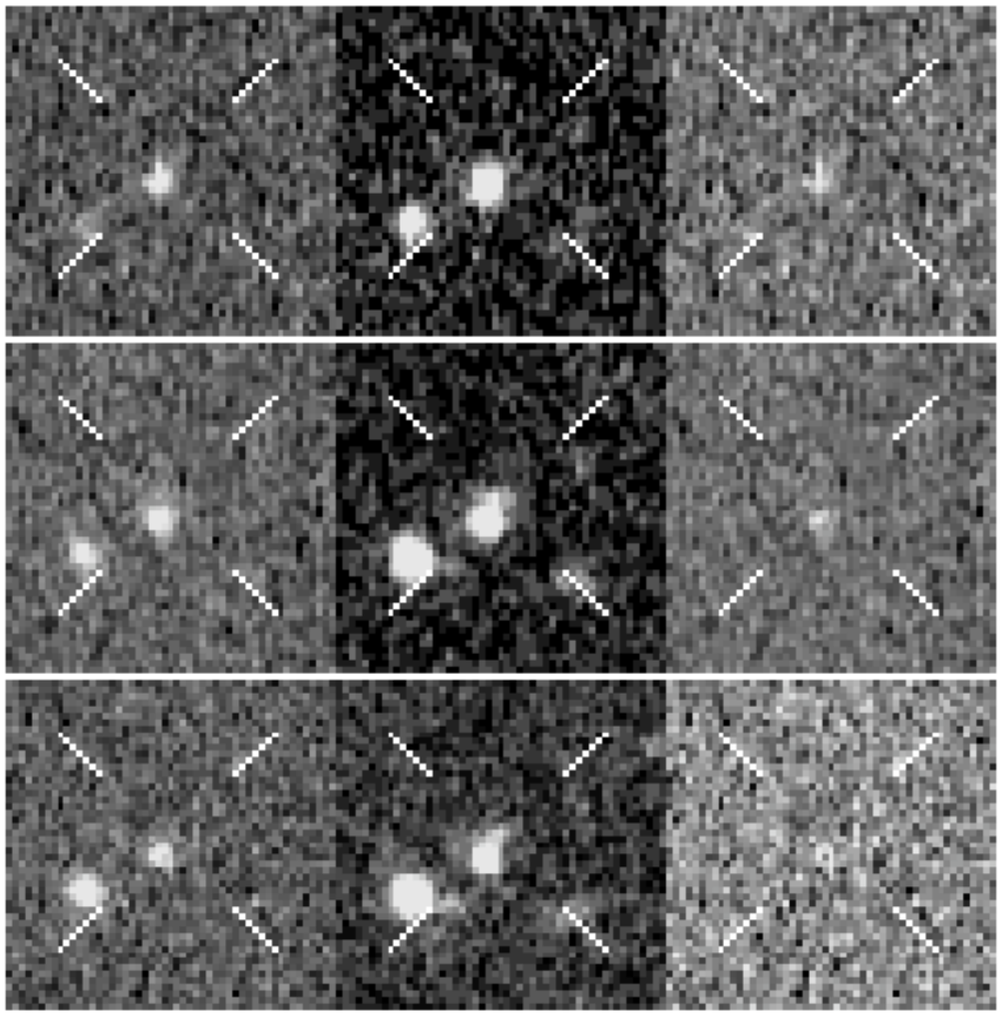
veto catalog

2005 season

- ~4000 objects transfered to Fermilab for human to scan
- ~400 of them tagged as SNe
- ~200 new "SNe" per night → SN candidates

http://sdssdp47.fnal.gov/sdsssn/sdsssn.html (**public**)
http://sdssdp47.fnal.gov/sdsssn_data/sdsssn.html (**not so public**)

search template difference



g

g (srch, tmplt, subtr)

r

r (srch, tmplt, subtr)

i

i (srch, tmplt, subtr)

Scanner	Sako	No updates	All
Obj Id	851735		
srun	5889	sfield	65
trun	826003	tfield	636
rr	10	cc	3
ra	44.457577	decl	-0.352280
gmag	21.988	g_delta	0.14
rmag	21.829	r_delta	0.50
imag	22.059	i_delta	0.48
Flags			
Ttl Objects	54		
# Scanned	0		

Back to initializing page.

Manual Scan Guide

- [0] None
- [1] Artefact
- [2] Moving
- [3] Sat. Star
- [4] Dipole
- [5] Variable
- [6] Transient
- [9] Cosmic Ray
- [103] SN GOLD
- [102] SN SILVER
- [101] SN BRONZE
- [100] SN OTHER

Hand Veto

UPDATE

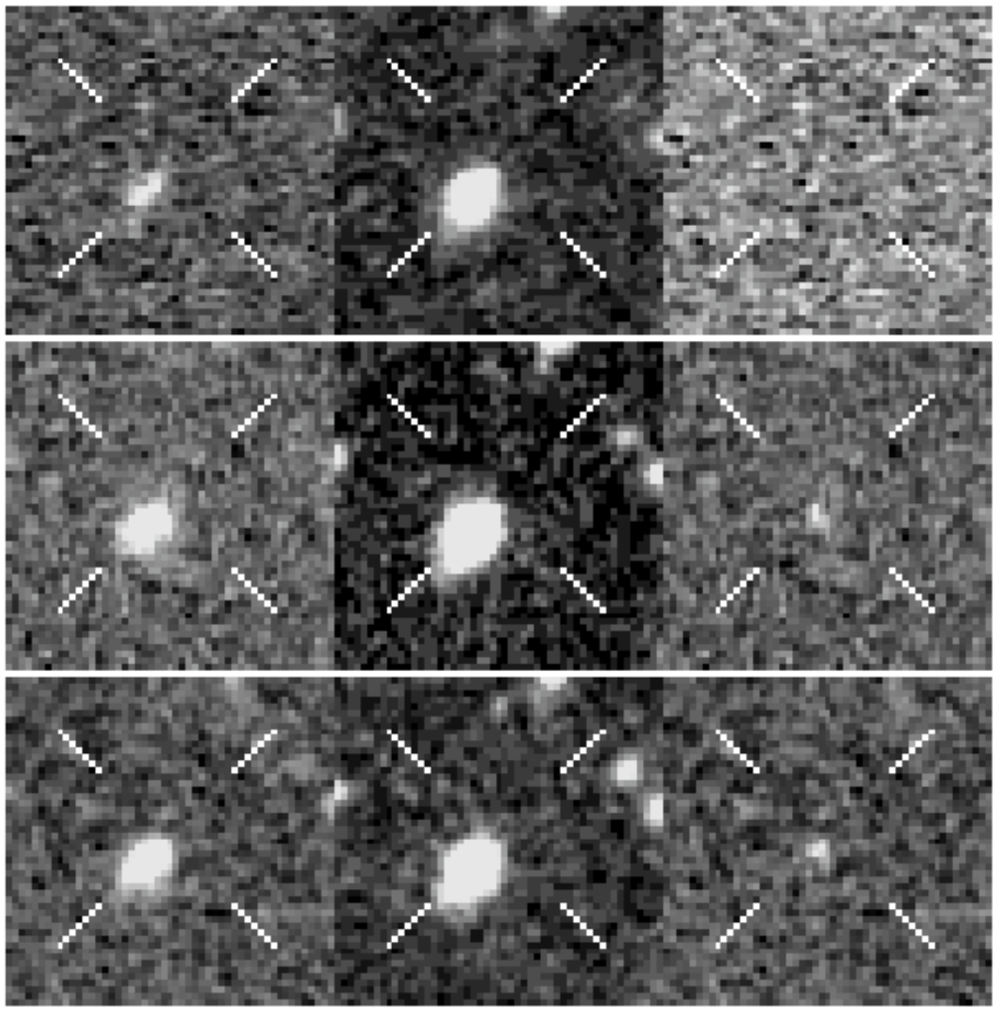
NEXT CAND/SKIP

History for Object Id 851735 By Position

Found 21 previous objects.

Obj Id	srun	trun	rr	cc	ra	decl	MJD	gmag	rmag	imag	Days Before
451485	5582	3325	10	3	44.45755	-0.35232	53622.4	21.75	21.6	21.7	73.9
511175	5607	3325	11	3	44.45755	-0.35232	53627.4	21.71	21.9	21.46	69
526815	5619	826003	10	3	44.45751	-0.35229	53634.4	0	0	0	62
526818	5619	826003	10	3	44.45754	-0.35228	53634.4	0	0	0	62

search template difference



g

g (srch, tmplt, subtr)

r

r (srch, tmplt, subtr)

i

i (srch, tmplt, subtr)

Scanner	Sako	No updates	All
Obj Id	851749		
srun	5889	sfield	68
trun	826003	tfield	639
rr	10	cc	3
ra	44.933941	decl	-0.343870
gmag		g_delta	
rmag	21.672	r_delta	0.20
imag	21.433	i_delta	0.20
Flags			
Ttl Objects	54		
# Scanned	0		

Back to initializing page.

Manual Scan Guide

- [0] None
- [1] Artefact
- [2] Moving
- [3] Sat. Star
- [4] Dipole
- [5] Variable
- [6] Transient
- [9] Cosmic Ray
- [103] SN GOLD
- [102] SN SILVER
- [101] SN BRONZE
- [100] SN OTHER

Hand Veto

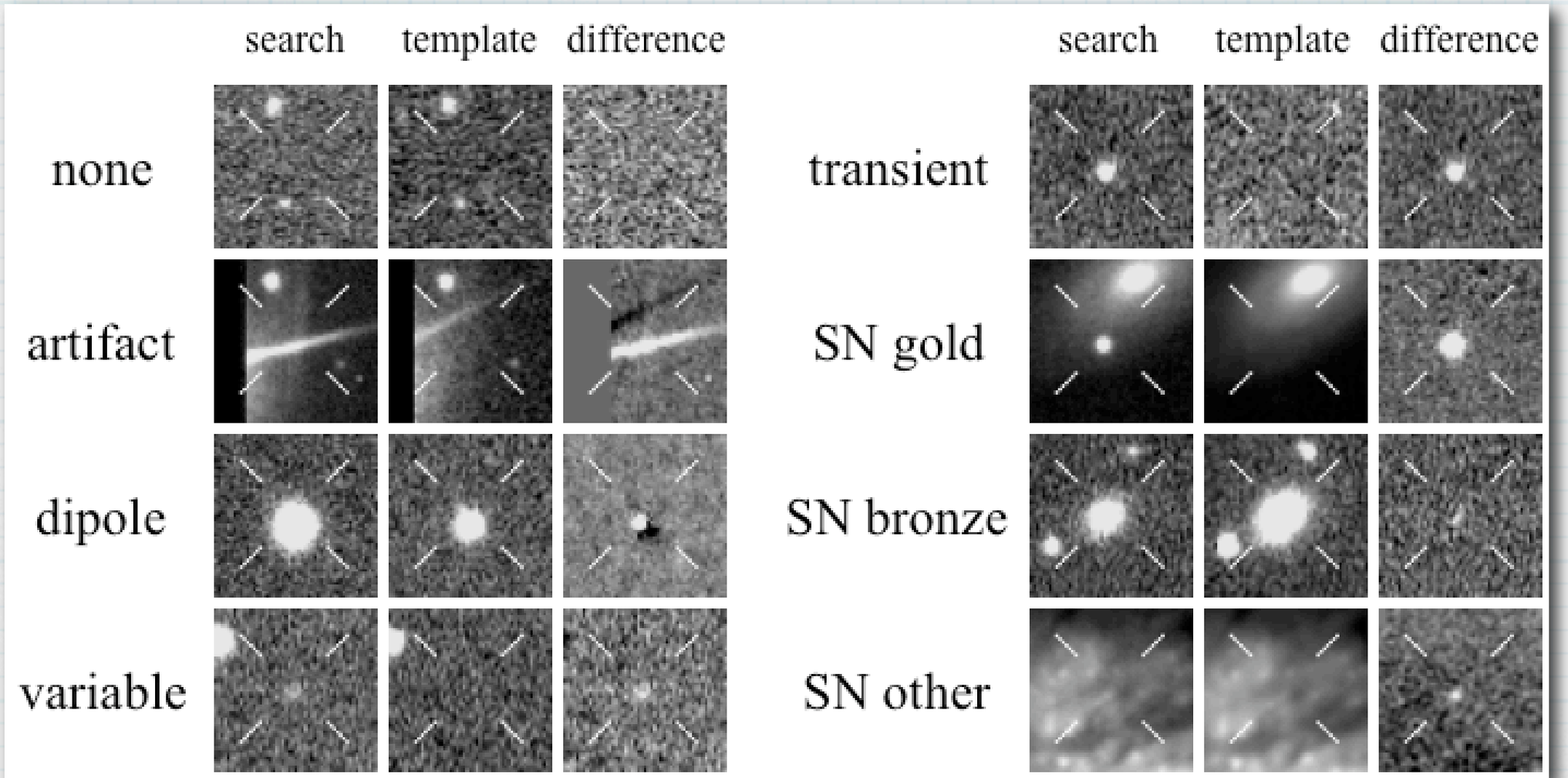
UPDATE

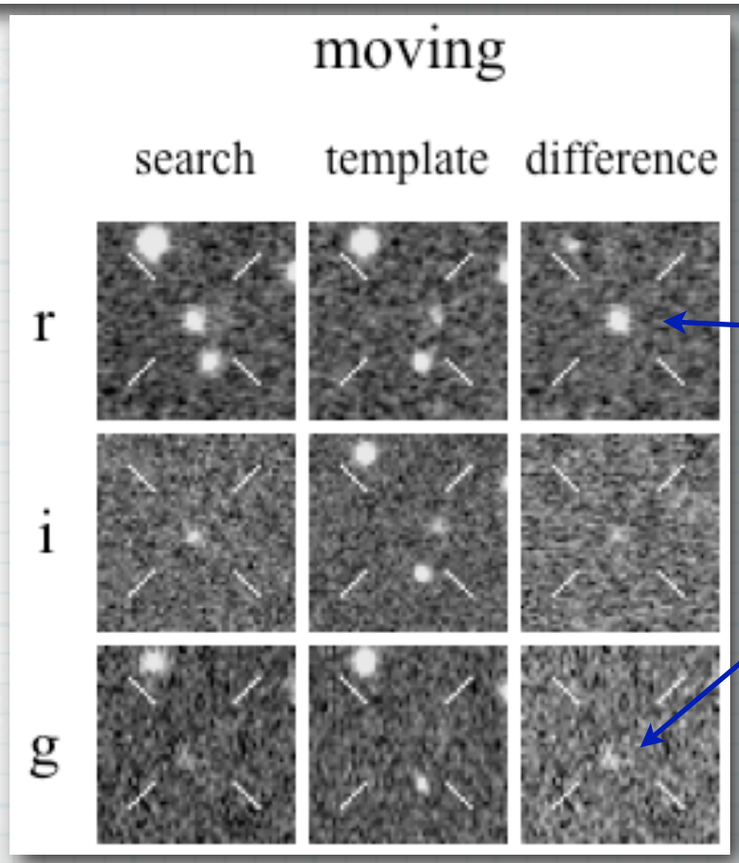
NEXT CAND/SKIP

History for Object Id 851749 By Position

Found 12 previous objects.

Obj Id	srun	trun	rr	cc	ra	decl	MJD	gmag	rmag	imag	Days Before
648741	5760	826003	10	3	44.93394	-0.3439	53665.5	21.94	21.78	21.95	30.9
668948	5771	826003	10	3	44.93397	-0.34385	53668.4	21.61	21.83	21.98	27.9
681316	5776	826003	10	3	44.93397	-0.34388	53669.4	21.6	21.65	21.56	27
682246	5782	826003	10	3	44.93395	-0.34388	53670.5	21.7	22.03	0	25.9



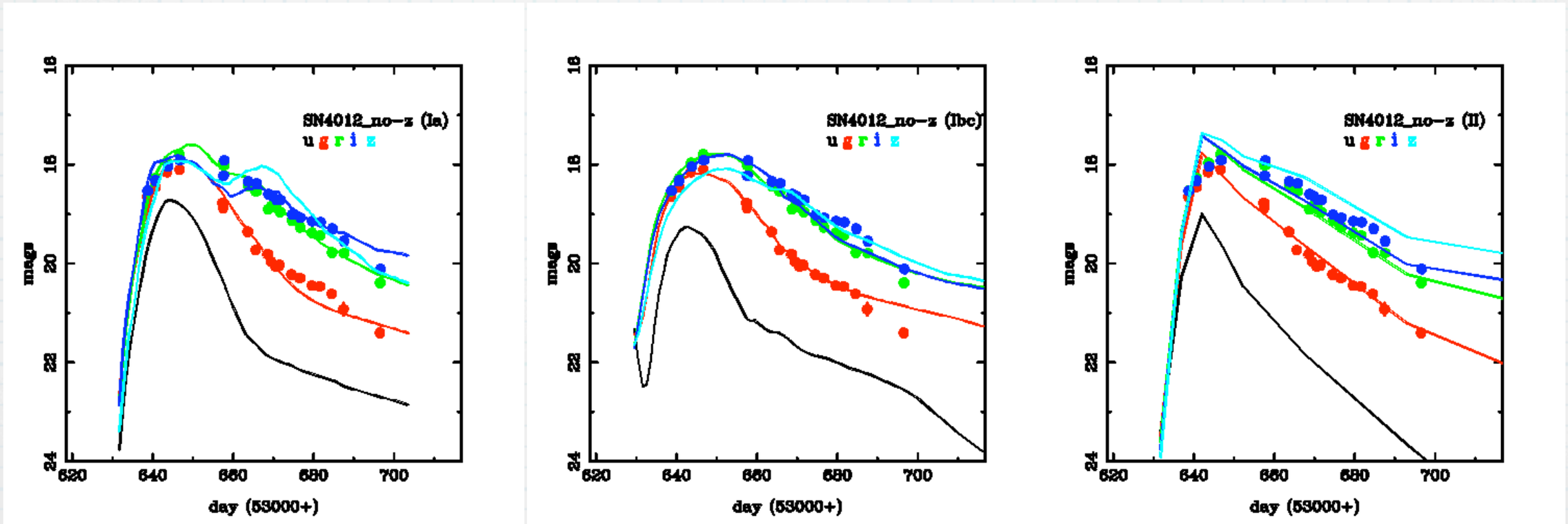


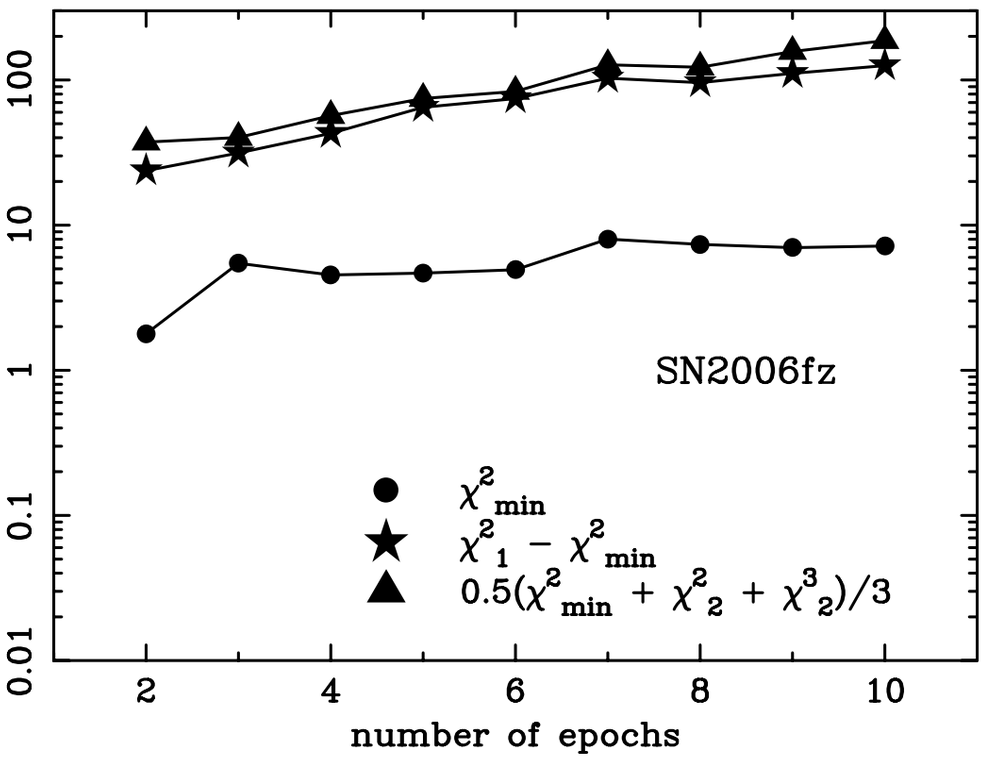
g and r band sources are not aligned → moving

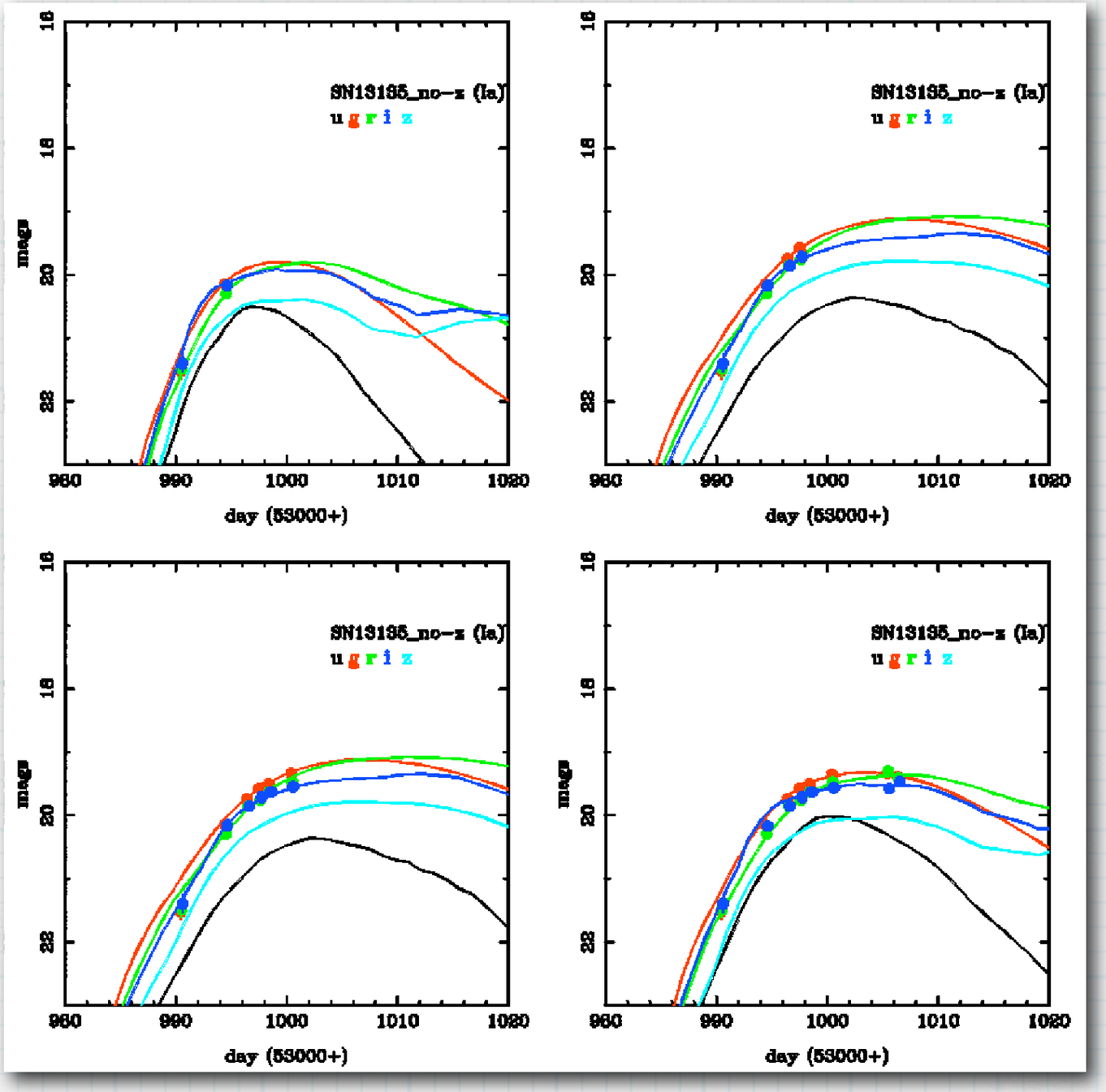
Sako et al. (2008)

Realtime Photometric Typing

* Typically, there are hundreds of active SN candidates.
* Compare light curves with library of Ia, Ibc, II templates.
* Select ~20 "good" targets for spectroscopic follow up.







Sako et al. (2008)

Spectroscopic follow up

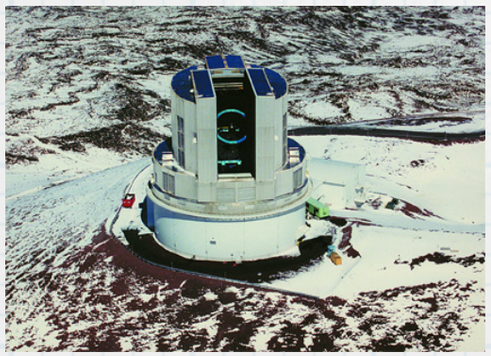
confirm type and measure redshifts

10m Keck

9.2m HET

2.5 m NOT

8.2 m Subaru



3.6 m NTT

3.5 m ARC

4.0 m KPNO

2.4 m MDM

mostly asteroids

improved junk filter trained with 2005 data

	2005	2006	2007
nights on 2.5m	59	60	55
runs	73	90	74
objects scanned	190,020	14,441	15,264
SN candidates	11,385	3694	3966
confirmed SN Ia	**130**	**197**	**171**
probable SN Ia	**16**	**15**	**21**
SN Ia host z	**81**	**13**	**-**

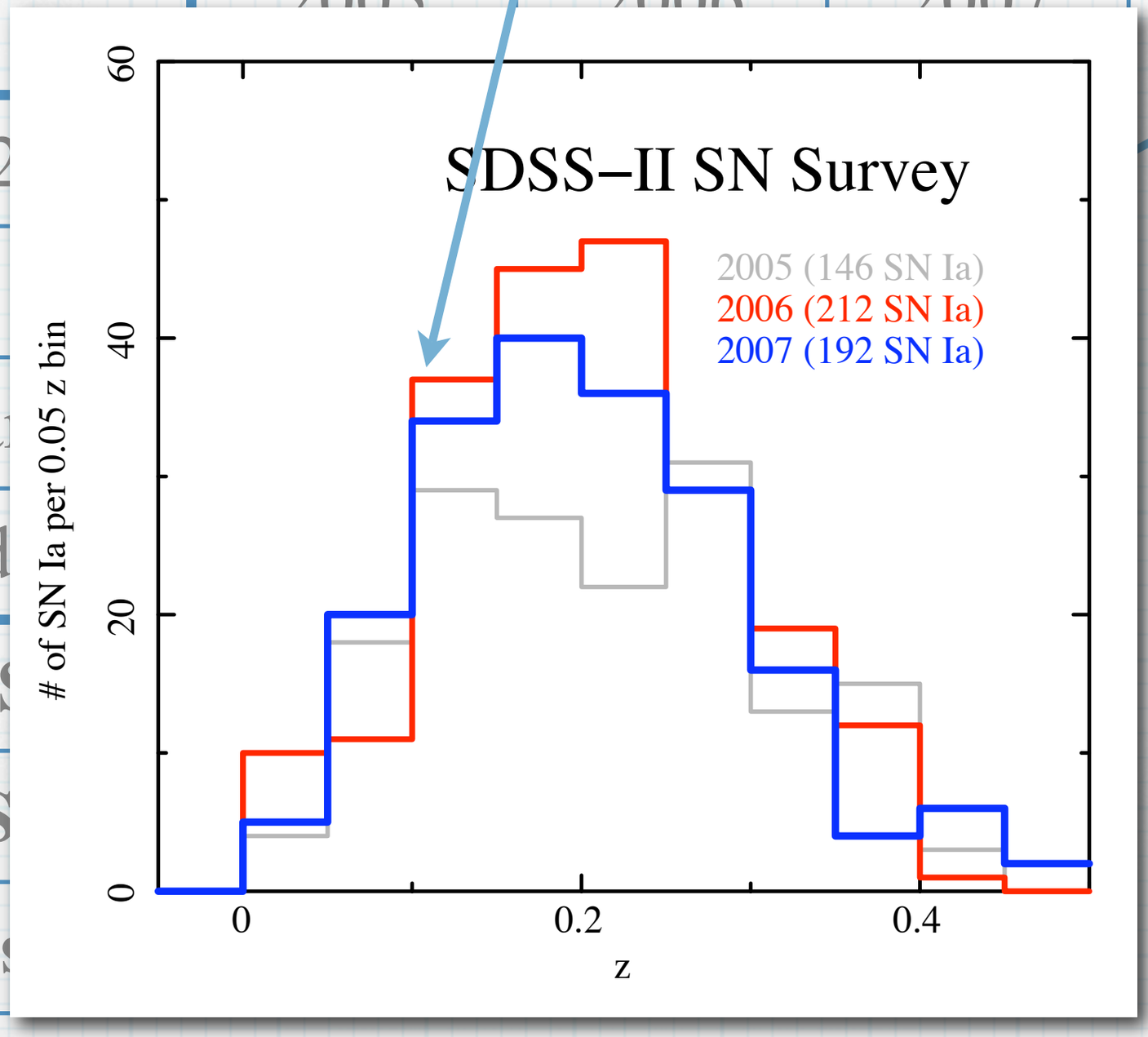
Sako et al. (2008)

498 SN Ia + 80 CC SNe in 9 months.

mostly asteroids

improved junk filter trained with 2005 data

	2005	2006	2007
nights on 2			
runs			
objects sca			
SN candid			
confirmed S			
probable S			
SN Ia hos			



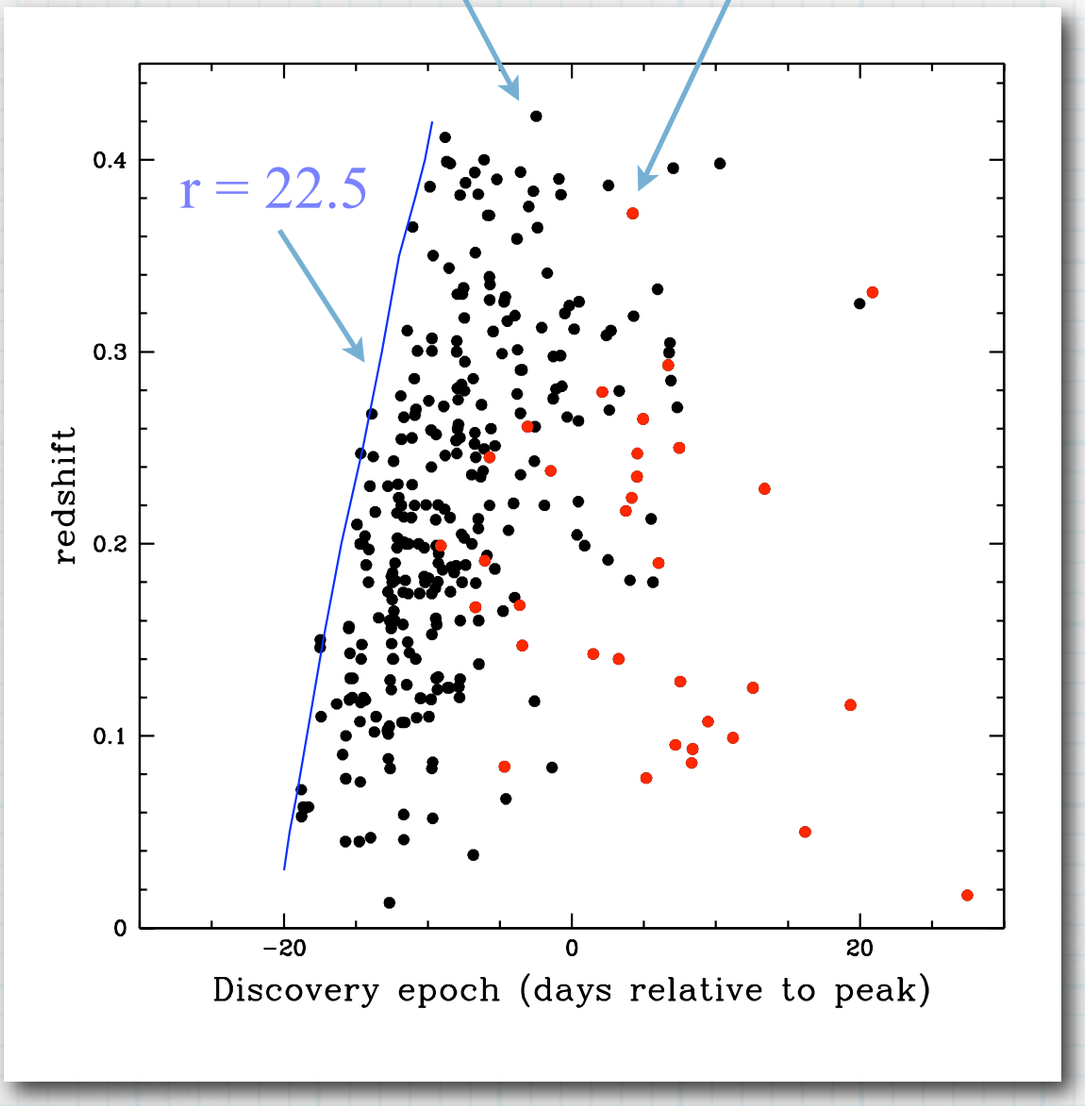
Sako et al. (2008)

498 SN Ia + 80 CC SNe in 9 months.

2005 & 2006 Seasons

peaked after Sept. 7

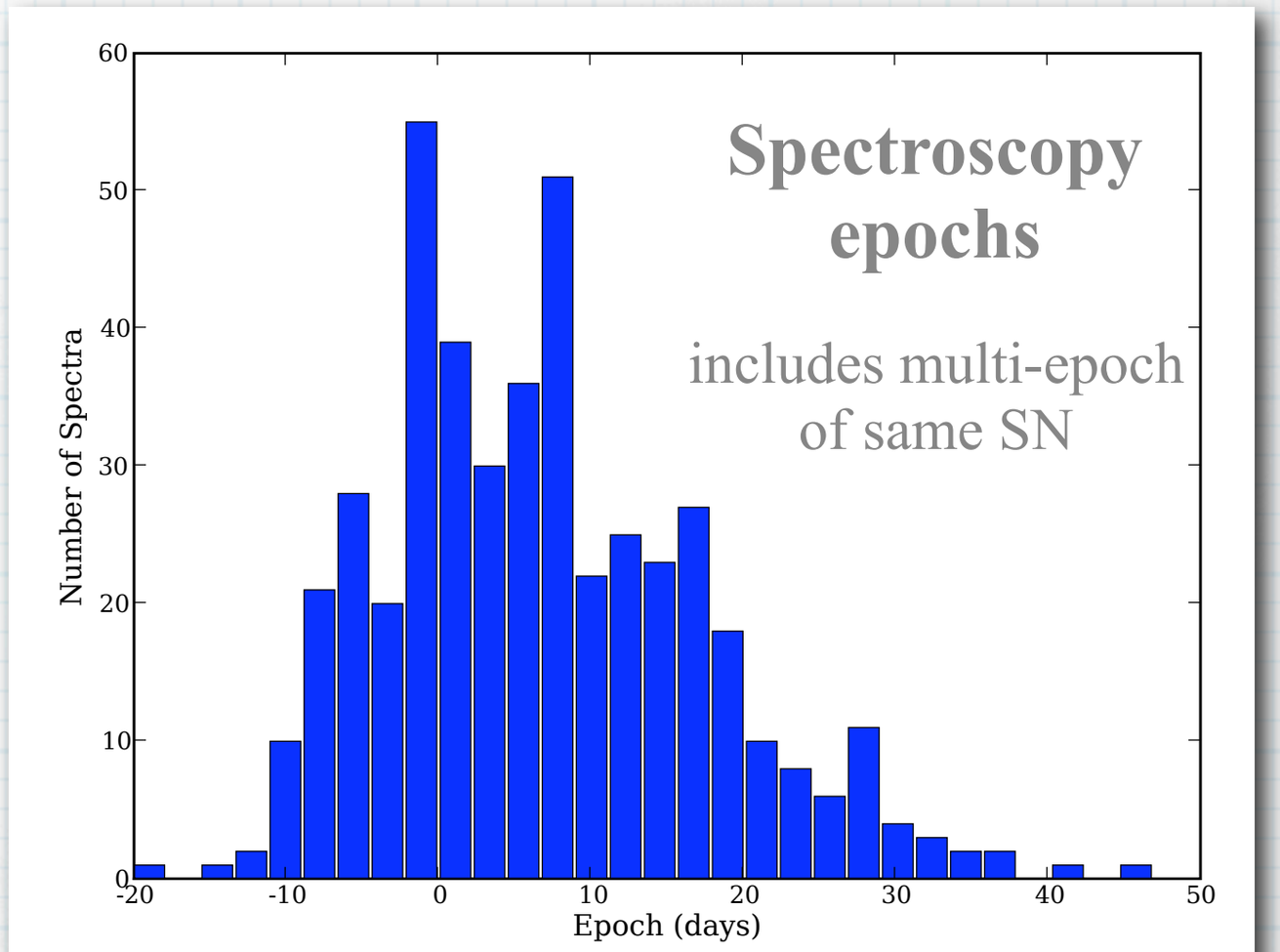
peaked before Sept. 7



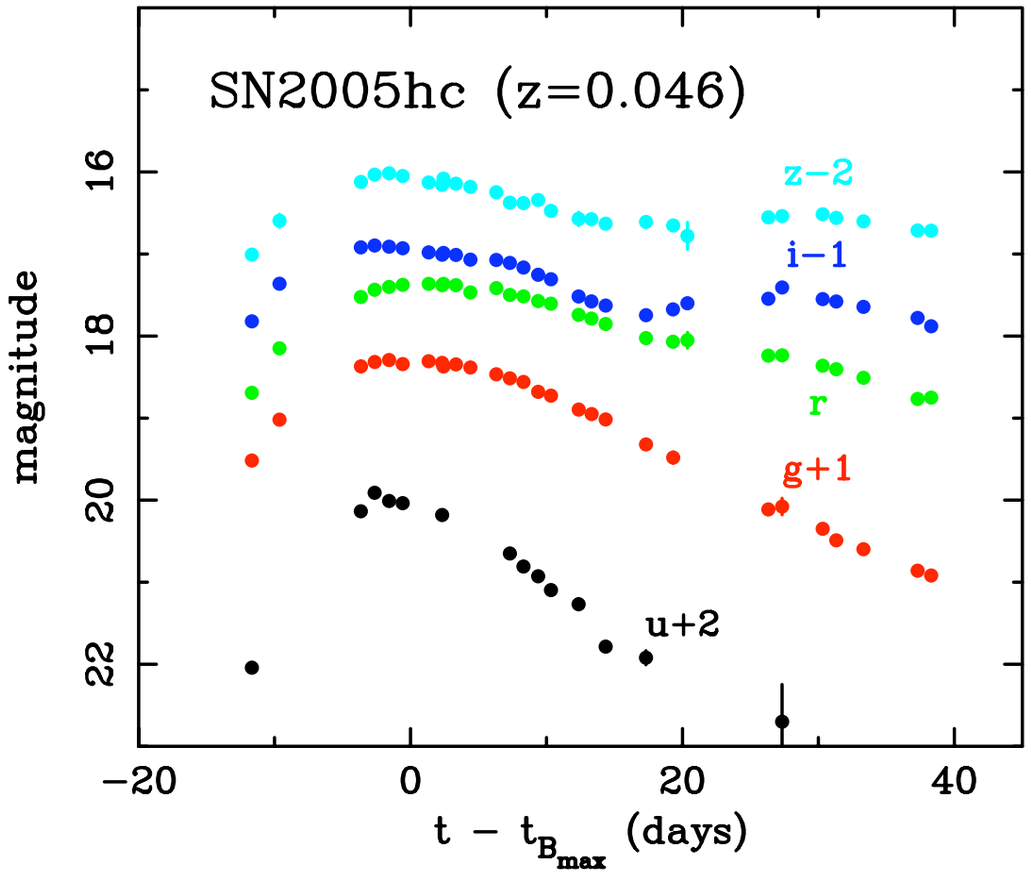
Frieman et al. (2007)

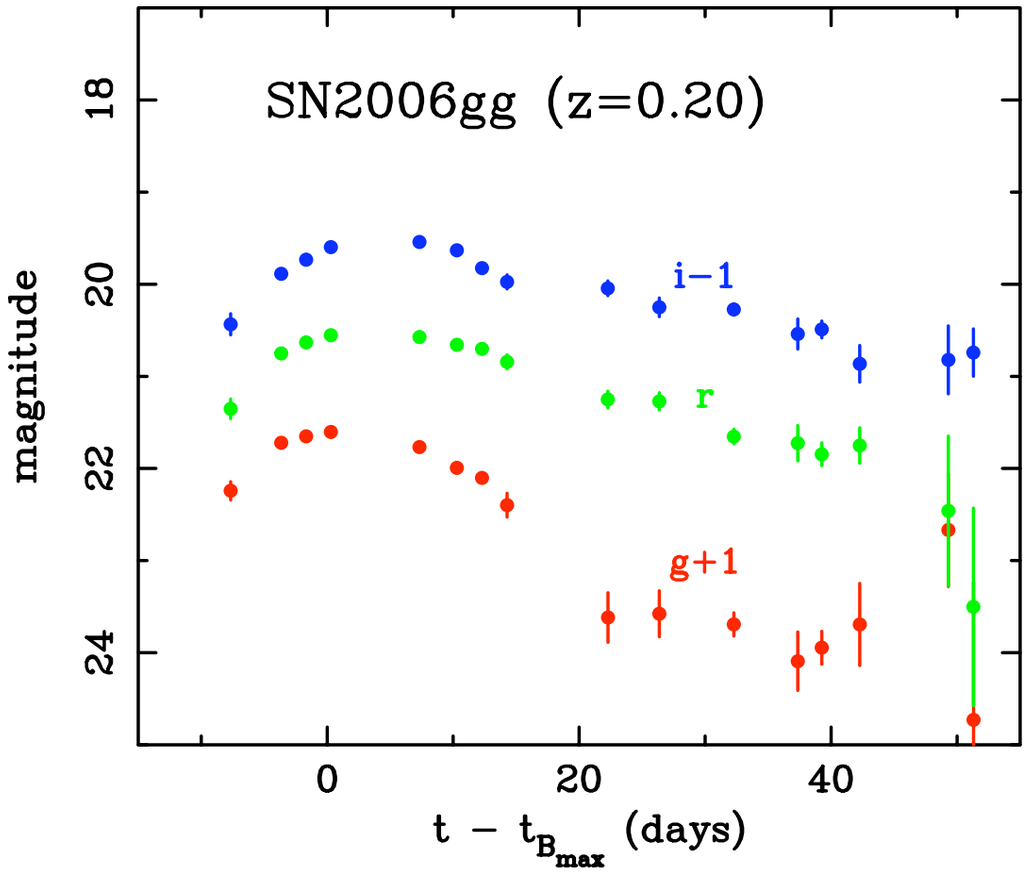
> 85% of SN Ia discovered before maximum light

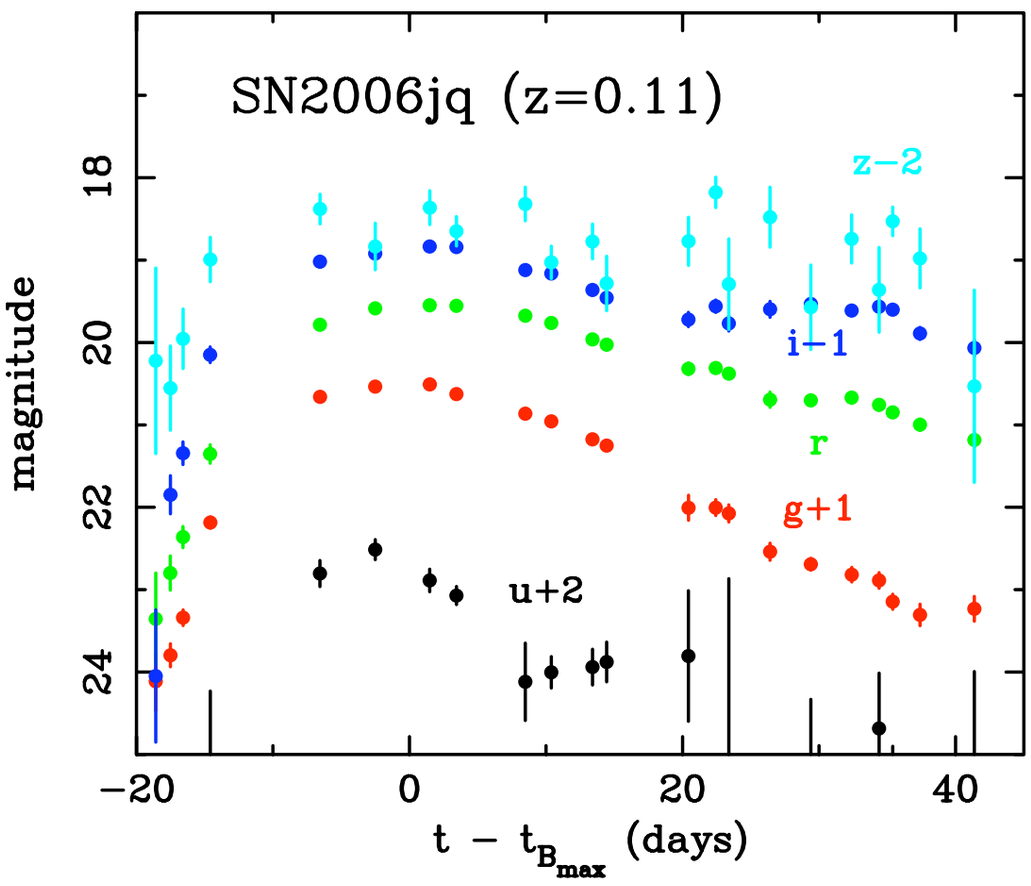
Follow-up spectrum usually obtained after **~2 - 4 epochs** (~90% confirmation efficiency for SN Ia).

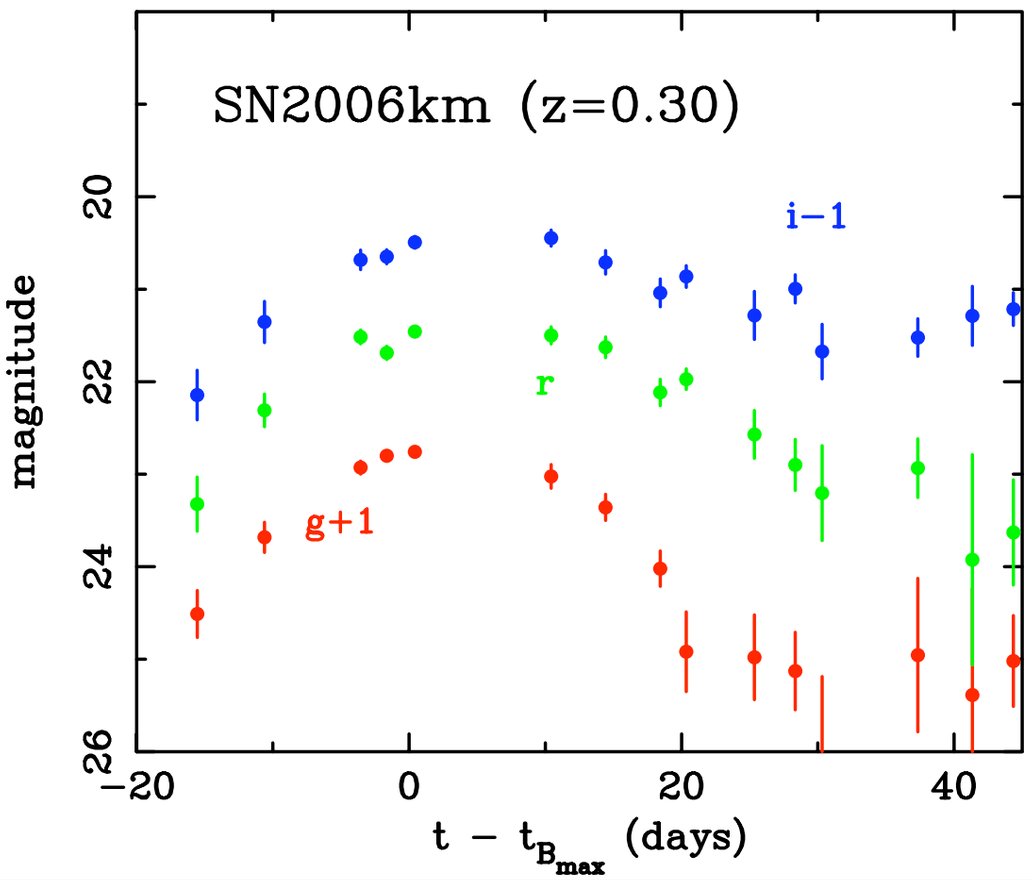


also attempted **20 single-epoch** candidates (**15** SNe, **1** galaxy, **2** noise, **2** asteroids)

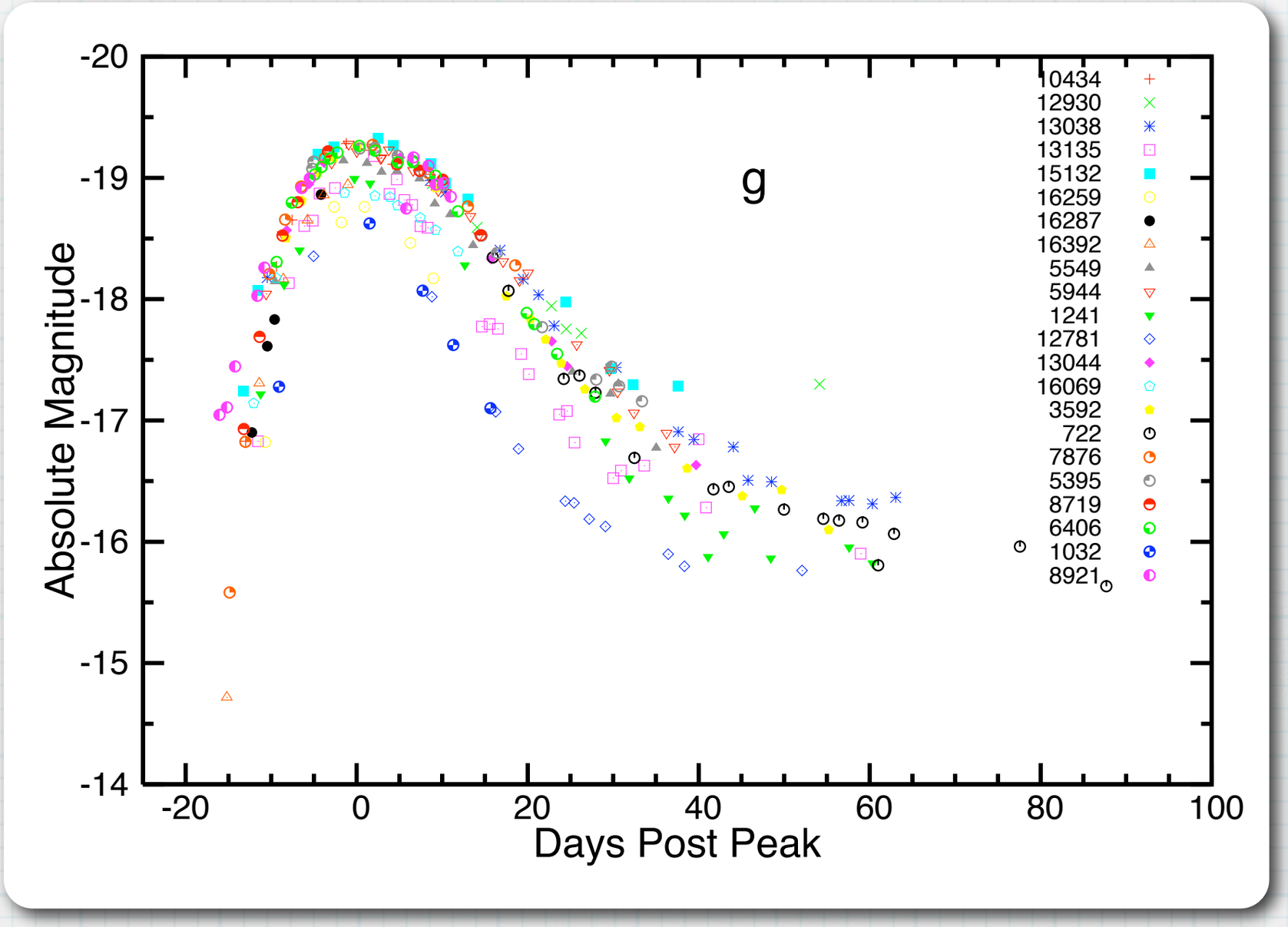

SN2005hc (z=0.046)
z−2
i−1
r
g+1
u+2
magnitude
16
18
20
22
−20
0
20
40
t − t_Bmax (days)


SN2006gg (z=0.20)
i−1
r
g+1
magnitude
18
20
22
24
0
20
40
t − t_Bmax (days)


SN2006jq (z=0.11)
z−2
i−1
r
g+1
u+2
magnitude
18
20
22
24
−20
0
20
40
t − t_Bmax (days)


SN2006km (z=0.30)
i−1
r
g+1
magnitude
20
22
24
26
−20
0
20
40
t − t_Bmax (days)

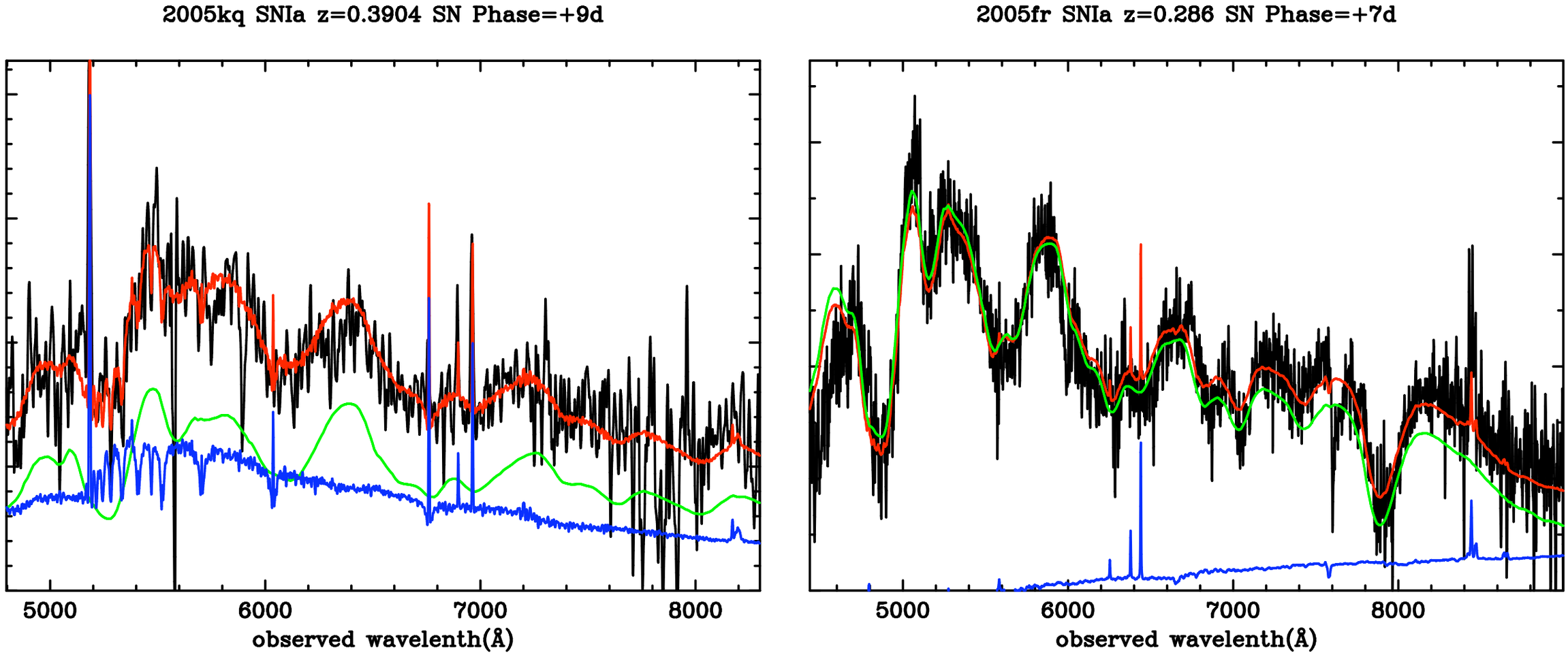
Low-z calibration/training



- well-calibrated photometry (flux and color)
- early light curve
- multi-epoch spectra for subset (study K-correction systematics)

Mosher et al. in prep.

Spectroscopy

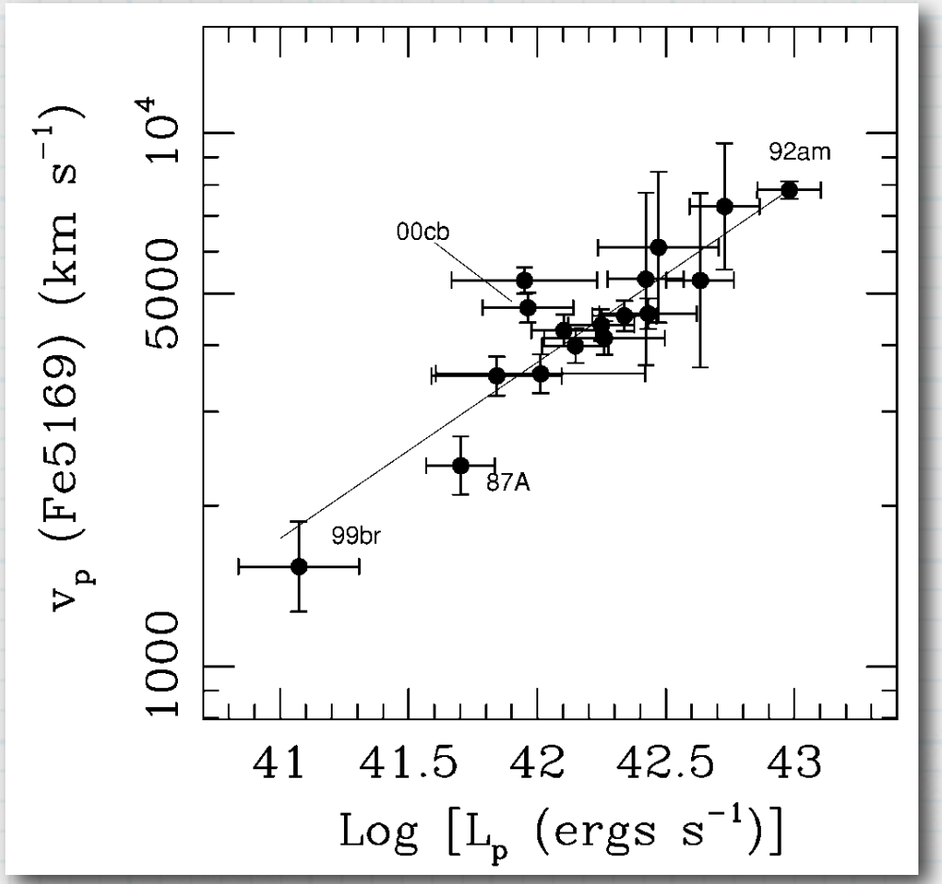


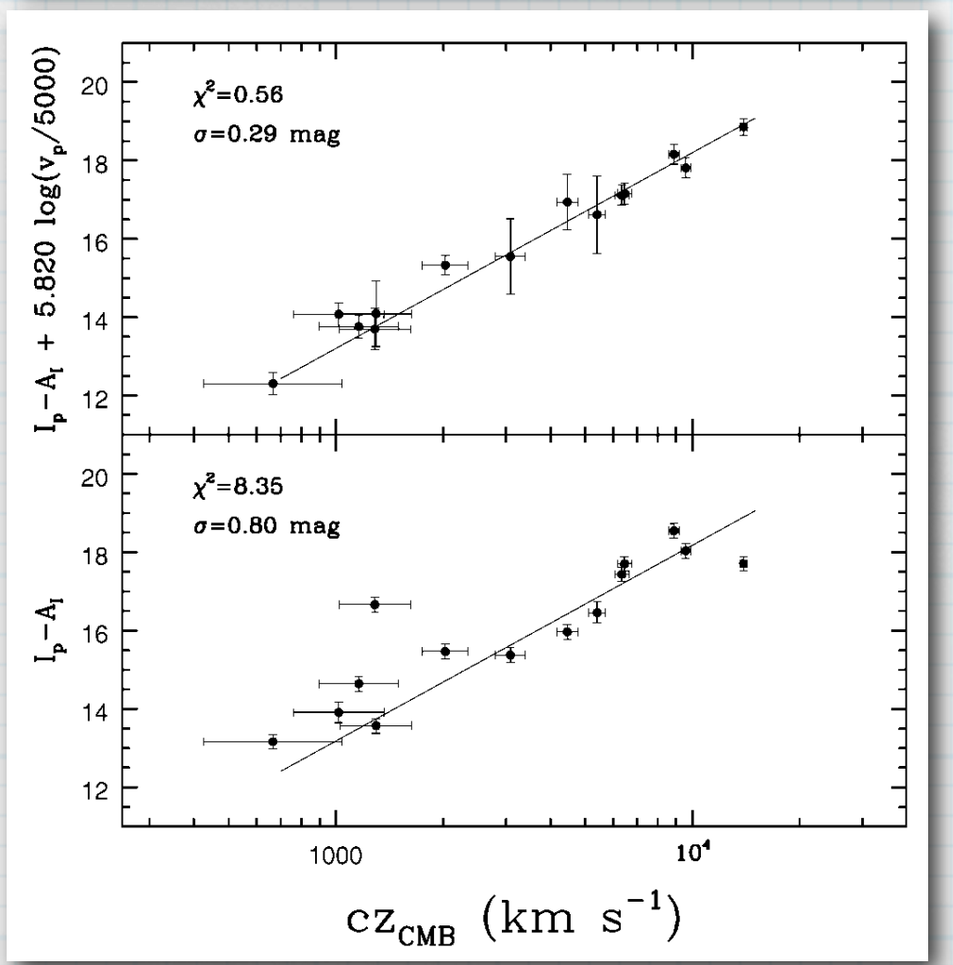
Zheng et al. (2008)

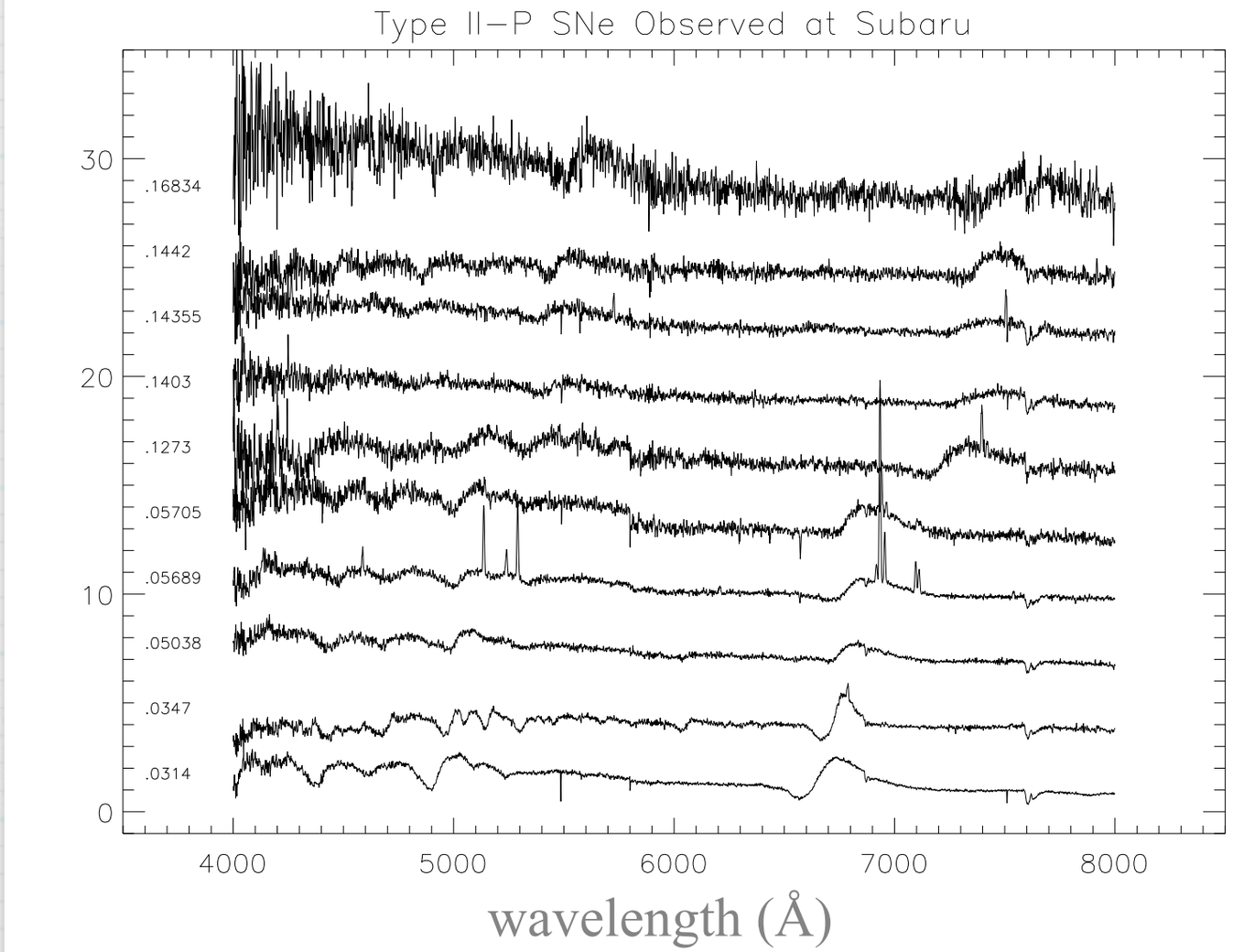
- total of ~1000 spectra taken in three seasons.
- multi-epoch spectroscopy of selected nearby SNe.
- work on host galaxy modeling and subtraction.

Hamuy & Pinto (2002)

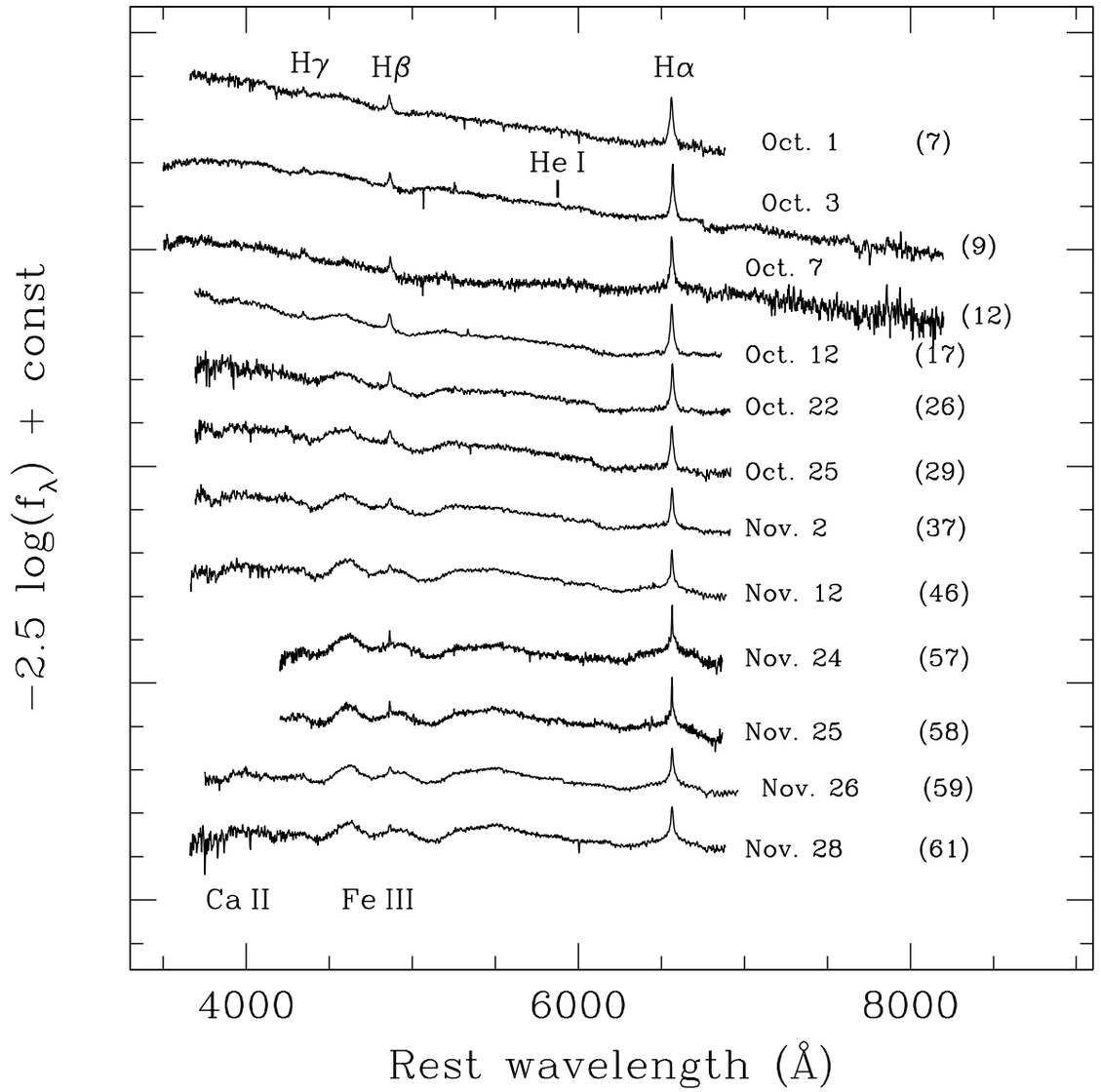
Type II-P as standard candles?

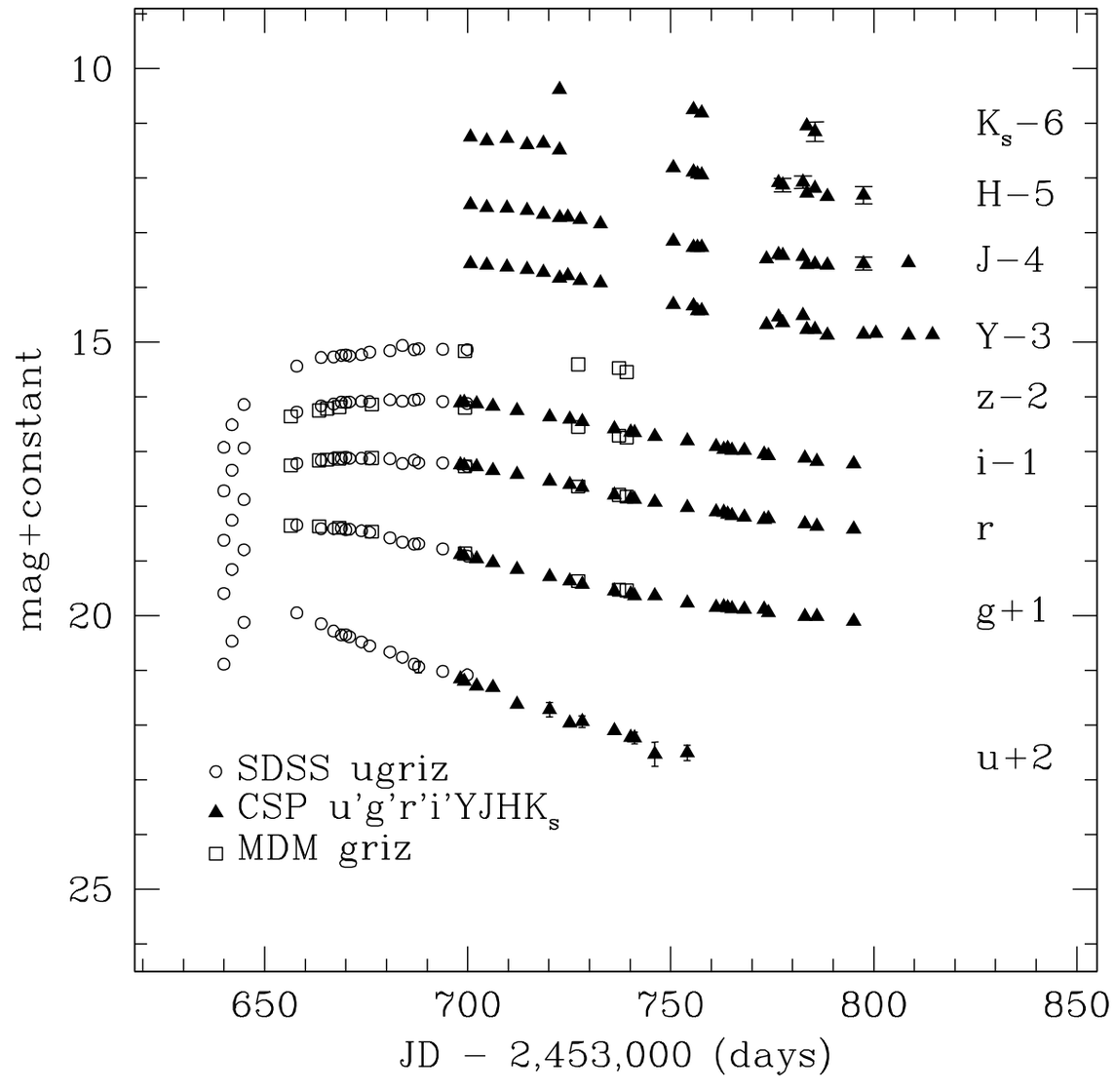






D'Andrea et al. in prep.





Prieto et al. (2007)

SN2005gj

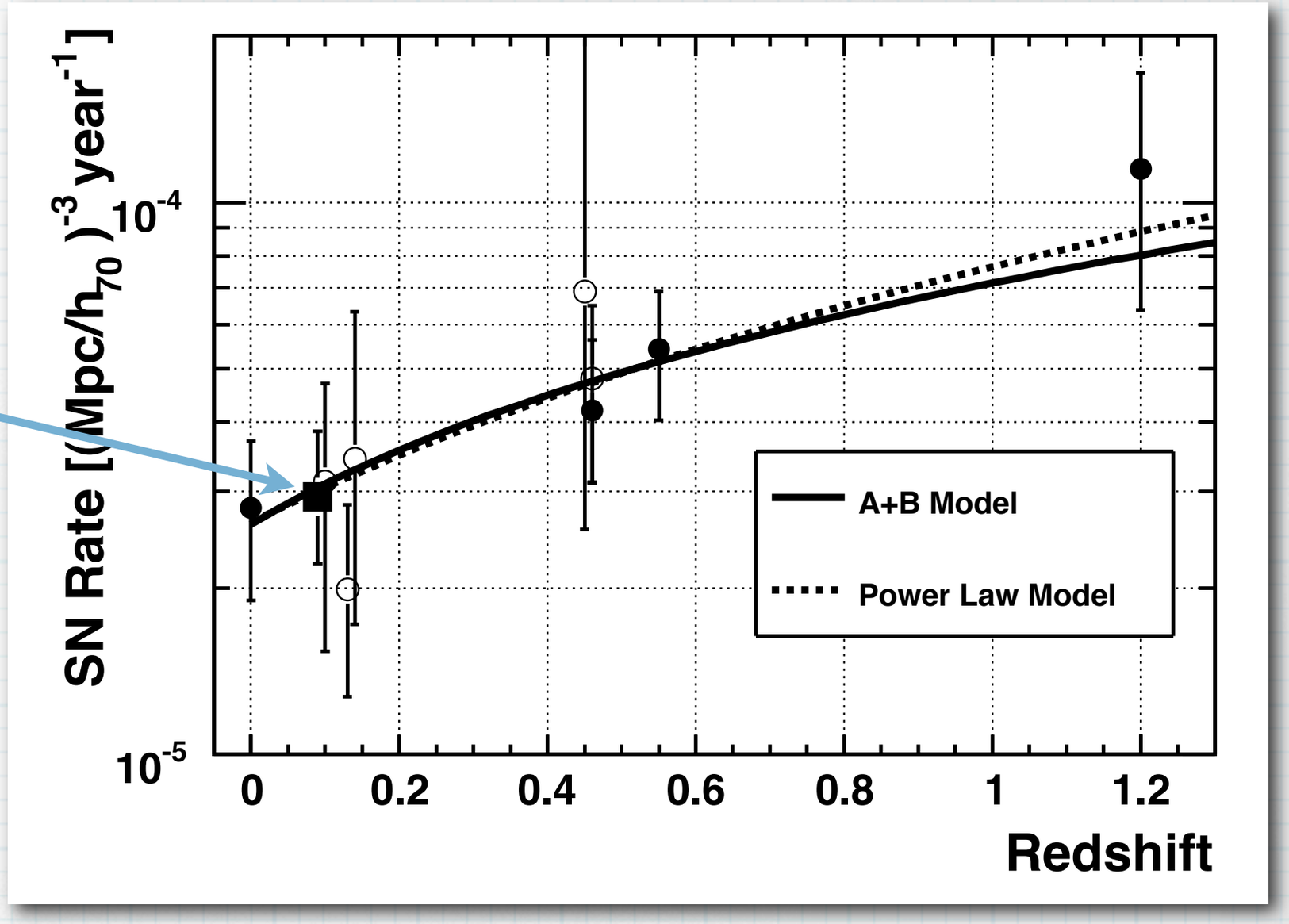
- co-discovered by SDSS-II & SNFactory
- SDSS + CSP + MDM data
- SN2002ic-like thermonuclear SN in dense environment?

Low-z SN Ia Rate

SDSS-II 2005 data
(17 SN Ia at z < 0.12)

- error dominated by systematic uncertainties

$$\frac{\sigma_{\rm stat}}{\sigma_{\rm syst}} > 5$$



Dilday et al. (2008)

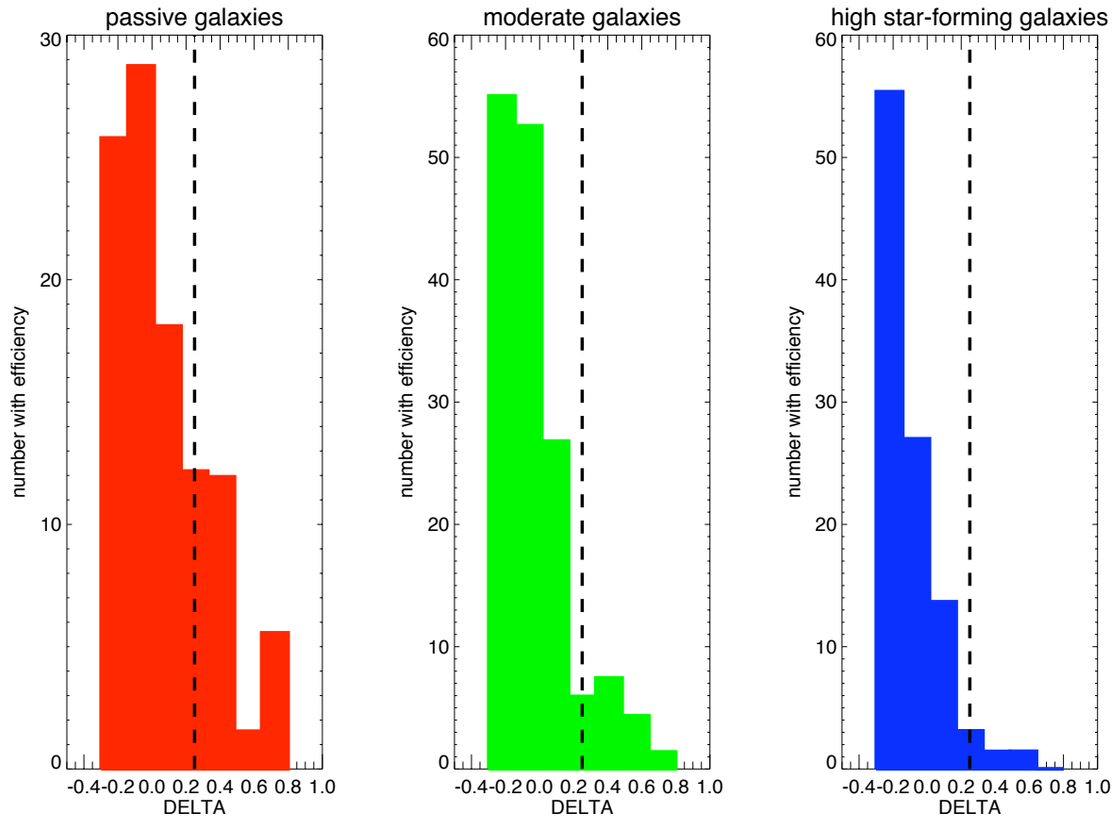
- blind search; well-understood efficiency.
- spectroscopic confirmation nearly complete out to z~0.15
- working to extend out to z~0.25

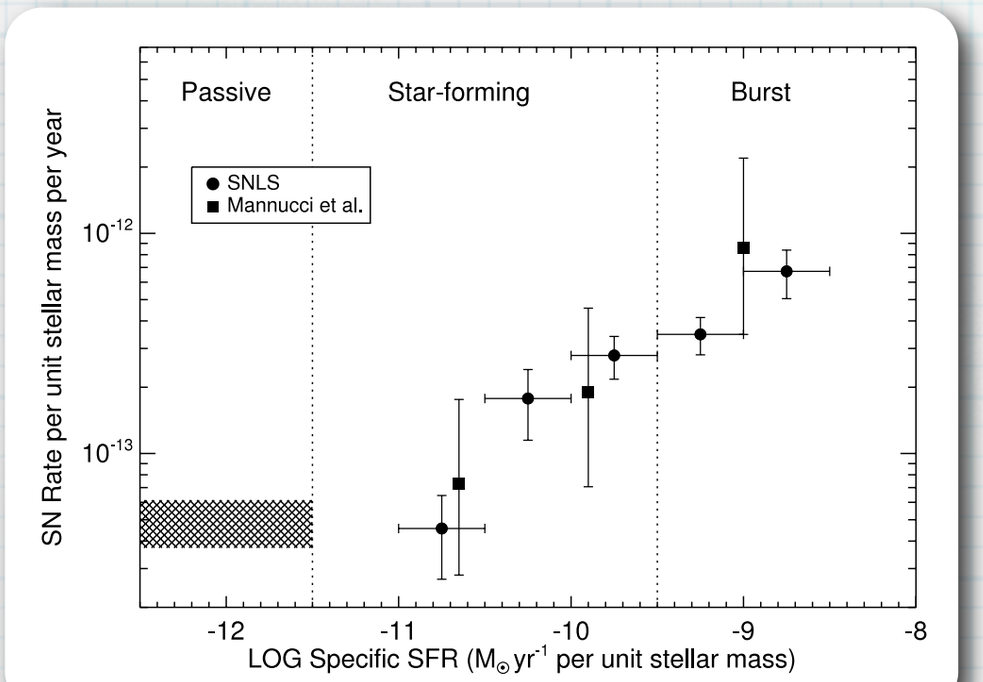
SN vs host properties

263 SNe Ia at z < 0.25

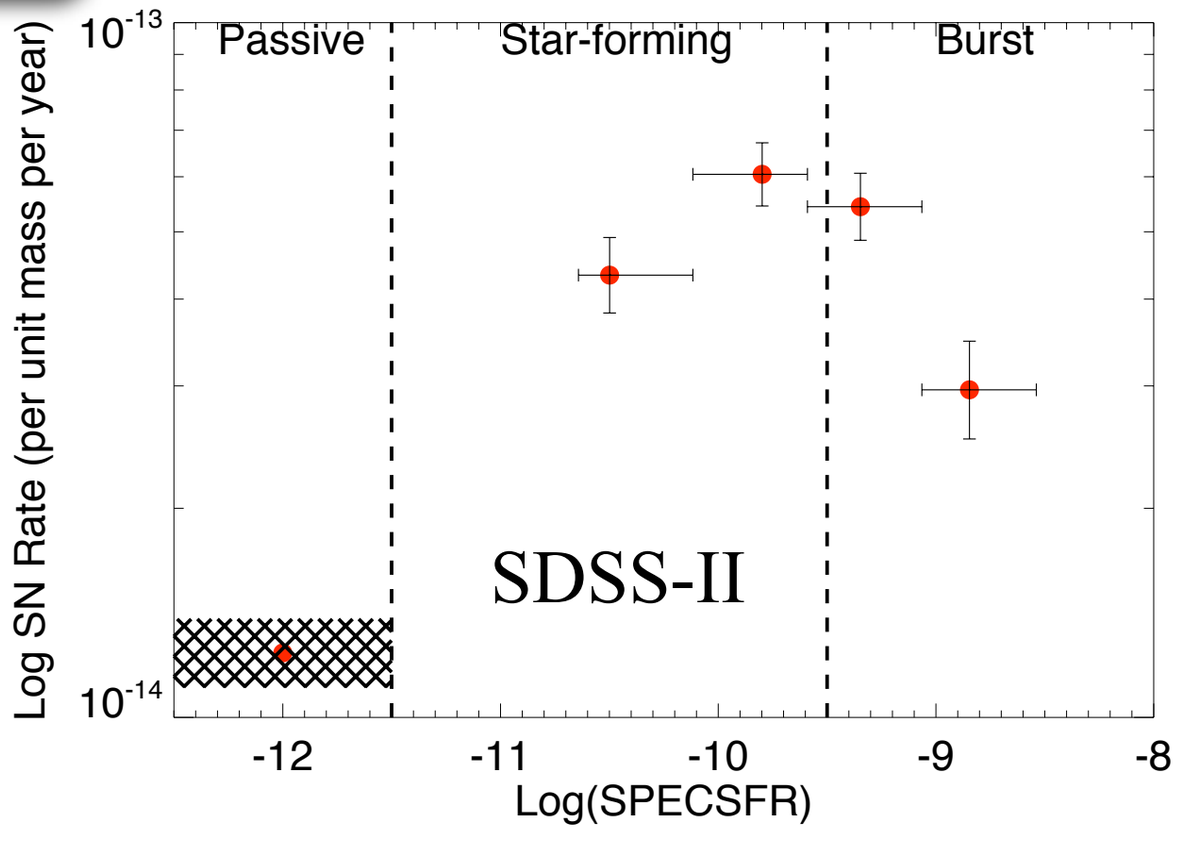
- estimate galaxy mass and SFR from flux and colors

SDSS-II data (Smith et al. in prep)



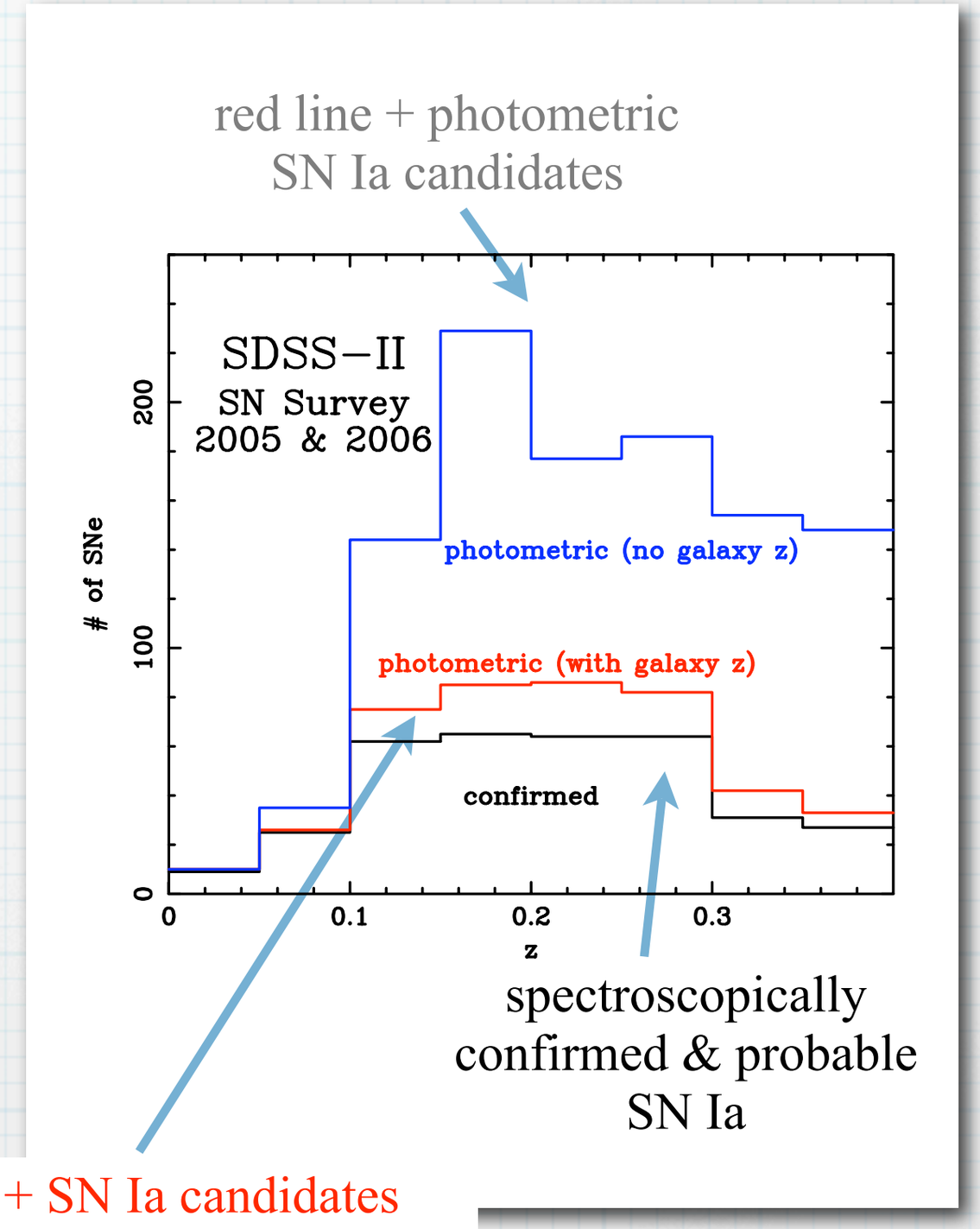


SNLS data (Sullivan et al. 2006)

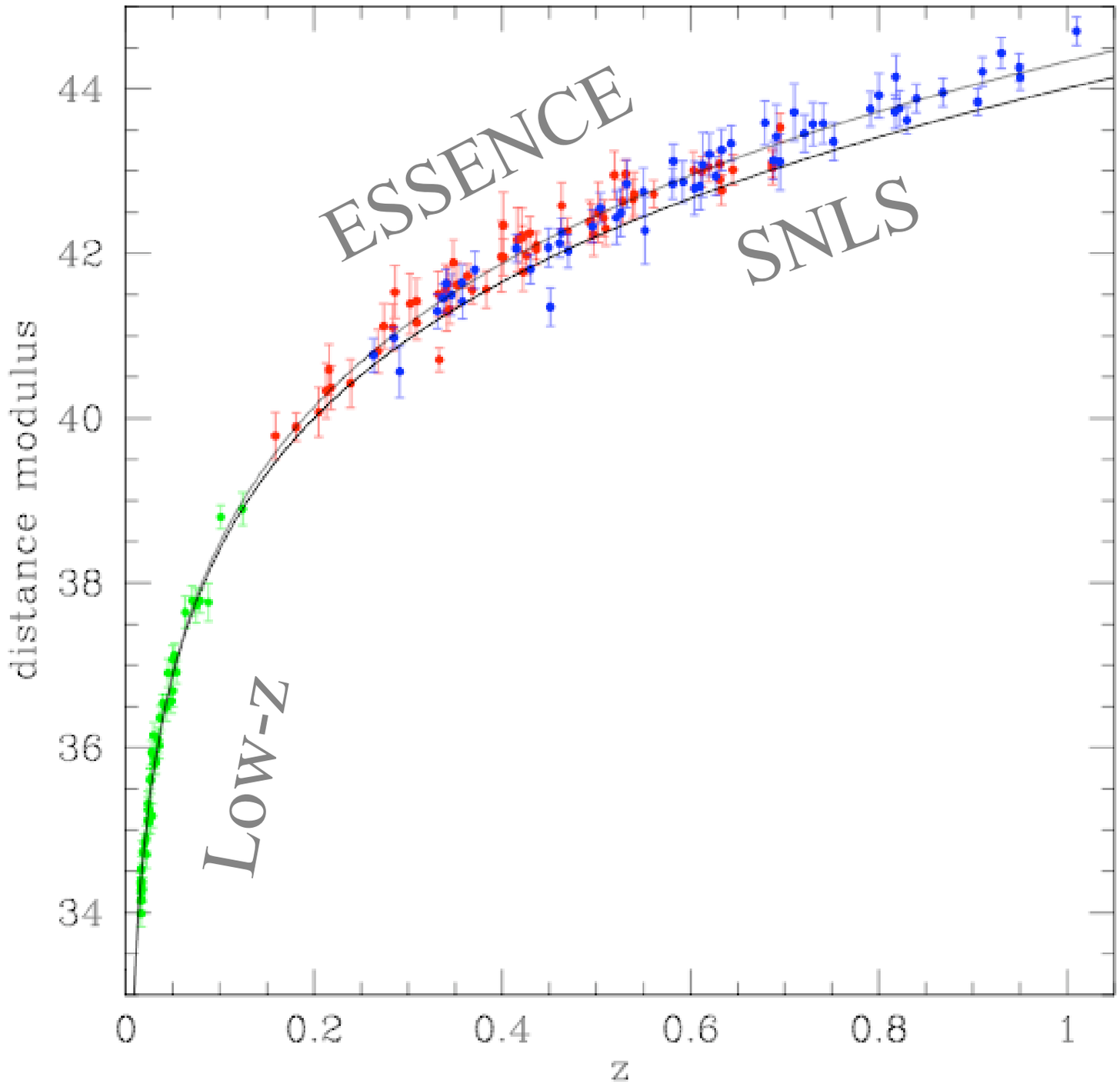


Photometric SN Ia Candidates

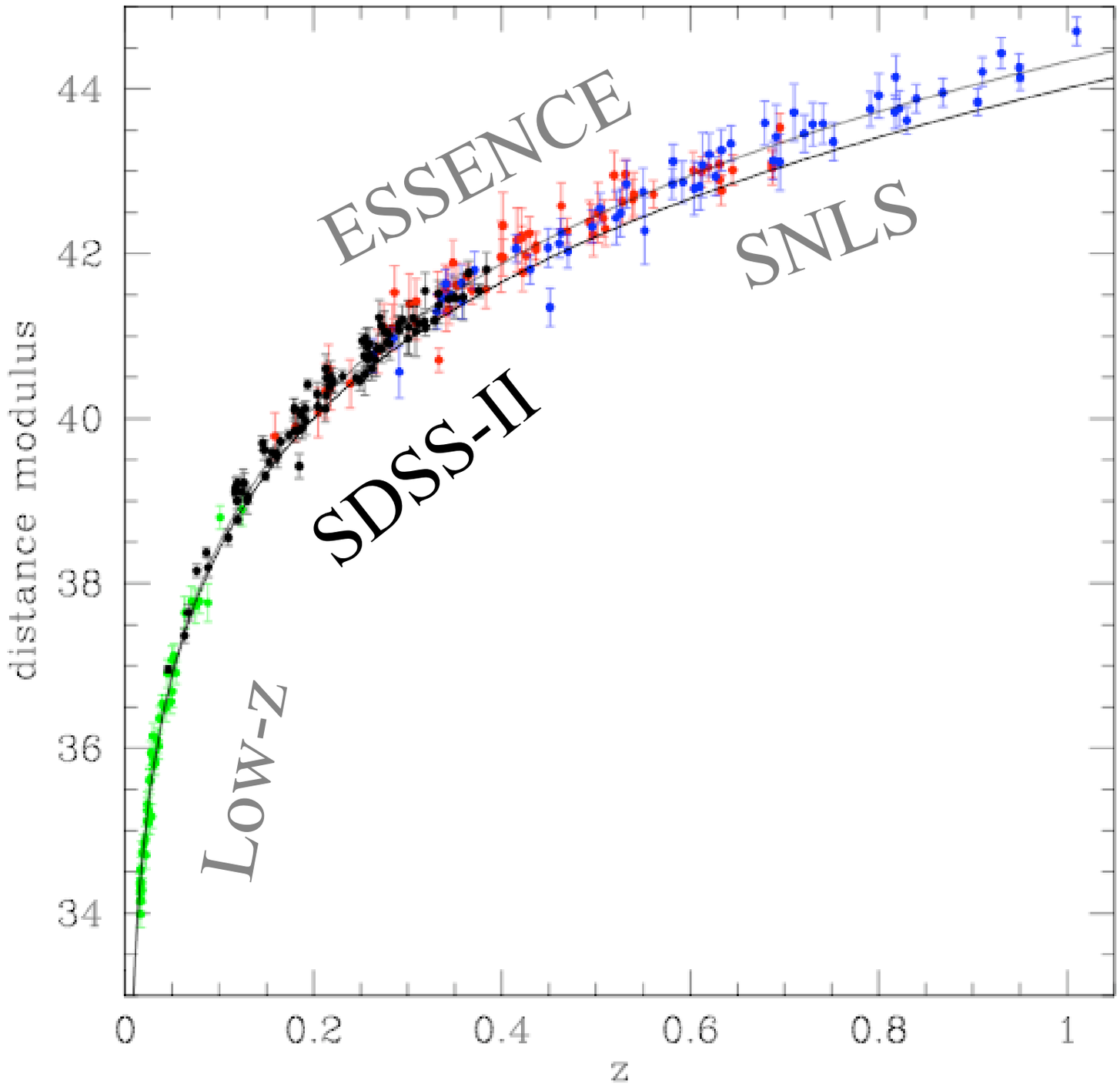
* Many candidates are not observed spectroscopically.
* Identified an additional ~650 high-quality photometric SN Ia candidates at $z < 0.4$ from (2005 - 2006 data)
  * continue to obtain host redshifts.
* Determination of the rate at $z \sim 0.3$.



SN Hubble Diagram



SN Hubble Diagram



2005 data

- 129 SN Ia
- 89 after cuts

results out soon...

Self-Contained Cosmology Analysis